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CHANNEL FORM AND PROCESS IN SPRING-DOMINATED CHANNELS

by
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Channel Form and Process in Spring-dominated Channels

Report to the National Forest Service

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INTRODUCTION

National Forests were created in order to furnish a continuous supply of timber and secure favorable water flows for the needs of the country. In order to meet these needs, the National Forest Service developed a Water Information Management System Handbook (USDA Forest Service, 1987). Chapter 30 of that handbook is titled "Procedure for quantifying channel maintenance flows." Channel maintenance flows are defined as the range and duration of in-channel flows necessary to maintain stability and effective function of the existing stream channel. Channels which do not receive maintenance flows may experience changes in hydraulic geometry, capacity, flood frequency, erosion rates and/or rates of sediment deposition. Other changes can include the encroachment of the floodplain or vegetation.

Channel maintenance approaches have been developed for alluvial, snowmelt-dominated perennial streams. In some National Forests there is developing concern regarding the maintenance of channels that are dominated by flows from springs. In many of these cases, a full-blown stream emerges suddenly at springs. The channels below springs often provide special aquatic and riparian habitat. In some areas, the springs are located in relatively dry regions and these spring-dominated streams are among the few perennial channels. Spring-dominated streams often have fairly uniform discharges through the year and hence the water in these channels may become attractive to off-stream users. The US Forest Service is considering how to approach the establishment of flow requirements to minimize channel degradation in spring dominated channels.

In this report we describe a preliminary investigation of spring-dominated channels. The report includes a literature review and field reconnaissance. In the investigation we compare spring-dominated streams and streams whose runoff is derived from snowmelt or rainfall directly. We will call these streams whose runoff is derived from snowmelt or rainfall directly, runoff streams. The term is meant to include surface runoff and shallow subsurface runoff. The main reason for the detailed comparison between runoff and spring-dominated streams is that methods already exist for setting maintenance flows in runoff channels (Chapter 30). The present methods serve as a logical starting point for an examination of channel maintenance issues in spring dominated channels. Nonetheless we will consider the appropriateness of transferring current methods for channel maintenance to spring-dominated channels. Finally we will make a set of recommendations to the Forest Service on the protection of the spring-dominated channels. Riparian maintenance flows is an issue that we will discuss briefly.

Alluvial Channels

Alluvial channels have banks which are composed of unconsolidated sediment, deposited by the streams which occupies the channel. Such channels are more readily adjusted to changes in flow than channels which are cut into bedrock. Spring-dominated channels and runoff-dominated channels may be alluvial or bedrock channels. We will consider form and process of spring-dominated, alluvial channels.

A general framework to understand alluvial channels has been built after decades of field, laboratory and theoretical research. In general it is understood that alluvial channels are self-formed and self-maintained. Their character is determined by the runoff and sediment load they receive. Flow in channels varies during the year and from year to year. Floods that spill out of the banks occur 2 out of 3 years on average - - this is equivalent to a recurrence interval of 1.5 years (Wolman and Leopold, 1957; Dunne and Leopold, 1978; Williams, 1978). During most of the year there is far less water in the channel; baseflow represents fair-weather drainage of deep groundwater and delayed subsurface flow. Baseflow is commonly 1-2 % of the bankfull discharge. Average annual discharge is about 10-15 % of the bankfull discharge (Dunne and Leopold, 1978).

Alluvial channels receive sediment from hillsides, from tributaries, and from erosion of the river banks and bed. The size of the material is largely determined by the watershed character: geology, size, geometry, climate and history. Most natural channels are viewed as being in balance; the channel dimensions and elevations are adjusted to the load and discharge supplied from upstream. This balance does not mean that the channel is static - - in fact one bank is eroded while sediment is deposited on the opposite bank - - but rather it means that there is some equilibrium and characteristic form. This equilibrium form is expressed in the channel's hydraulic geometry, which describes the relationship between channel width, depth, and velocity as they vary with discharge.

The maintenance of the channel is conceptually linked to the effective or dominant discharge - - that flow which over time transports the most sediment and is therefore thought to be most responsible for creating the channel dimensions (Wolman and Miller, 1960; Andrews, 1980). While very large floods move prodigious amounts of sediment because the amount of sediment moved is exponentially related to discharge, these floods occur so infrequently that they are not as important in total as events which recur about every 1.5 years. In many alluvial

streams, the effective discharge and the bankfull flow are thought to be equivalent since they have the same frequency (Wolman and Miller, 1960; Andrews, 1980).

The range of flows is also important in alluvial channels. Baseflow helps maintain the channel in various ways: by sustaining riparian vegetation which stabilizes the banks, by keeping surfaces saturated which prevents encroachment by riparian vegetation, and by keeping channel sediments moist so that channel bed cementation does not occur. Discharges below bankfull also move some sediment through the channel and may locally clean the bed of fine sediments (Reiser et al., 1985). Flows greater than bankfull deposit sediment on the floodplain and thus act to maintain the elevation and fertility of these areas. Greater-than-bankfull flows also may play a role in channels and valleys by providing appropriate substrate materials and conditions for riparian plants and by locally tearing up channel-bordering vegetation to initiate successional patterns.

If there are changes in the amount of water or sediment supplied from upstream, an alluvial channel is likely to respond by adjusting its dimensions to the new conditions. The nature of the change has been qualitatively described by Lane (1955) as $Q_s d \sim Q_w S$ where Q_s is the sediment load, d is the depth, Q_w is the water discharge, and S is the slope of the stream. If for instance, the water discharge were to decrease, the channel might respond by carrying less sediment downstream and, by flow continuity, decreasing its depth. Tributaries will continue to supply sediment however, so the channel will respond to the decrease in flow by depositing sediment and aggrading. This conceptualization of the interplay of variables is generally valid but does ignore other potential transitory responses including surface grainsize adjustment and removal of bars or other roughness elements.

Changes in the channel form often can be initiated or exacerbated by the encroachment of vegetation. As flows decrease, perennial vegetation is able to occupy sites within the former channel. When flows then return to the former channel, the vegetation acts to diminish the velocity of the flow which leads to deposition of material amongst the vegetation. In many cases the changes in discharge are the result of water diversion or impoundment. When floods do pass through a channel which has narrowed in part by the encroachment of vegetation, the active channel cannot carry the former bankfull flows and extensive and damaging floods occur. The headwaters of drainages may be particularly sensitive to these floods because diversion and storage structures usually do not reduce substantially the magnitude of the large floods, whereas they diminish substantially the flows below bankfull.

Classification of Springs

The classification of springs is discussed by several authors in detail (e.g., White, 1969; Jennings, 1985; White, 1988) and are summarized here. Water may reach the surface at springs by diffuse or conduit flow. Diffuse flow, or Darcian flow, is associated with flow through low-permeability rock and unmodified fissures (i.e. not enlarged by solution). In contrast are springs which exhibit conduit flow which is associated with flow through large cavities, often solution cavities. Springs may be associated with karst terrain or pseudokarst terrain. In karst terrain, landforms are produced by chemical solution of the bedrock (typically limestone or dolomite). In pseudokarst terrain, the landforms and/or hydrology are similar to that found in karst terrain, but are produced by processes other than solution. For example, areas underlain by basalt lava flows may exhibit pseudokarst features such as caves (lava tubes), sinking streams and springs. The Snake River Plain is an area, underlain by basalt lava flows, where some of the longest underground rivers in the world are found (White, 1988, p. 350). Springs discussed in this report are associated with pseudokarst developed in bedrock of volcanic origin.

Springs may be further classified as gravity, vauclusian and alluviated springs. Gravity springs have no significant hydrostatic head. Vauclusian springs are artesian and are named after the Fountain of Vaucluse in France. These springs can have significant hydrostatic heads. Alluviated springs are springs in which the groundwater rises to the surface through a significant thickness of alluvial deposits, such as glacial outwash (Powell, 1963). Springs are also classified as exsurgences and resurgences (Jennings, 1985, p. 46-47). Exsurgences represent the concentration of diffuse flow at a point. Resurgences represent the re-emergence of a former surface streams and are associated with conduit flow.

Rivers and streams fed by springs with diffuse flow will, in general, have a fairly steady flow without distinctive peaks in their hydrographs. On the other hand, springs with conduit flow respond rapidly to changes in recharge, much as surface rivers. This is particularly true for conduit systems that are dominated by allogenic recharge (streams in karst terrain are classified as allogenic if their headwaters are on impervious rock or autogenic if their begin their courses in karst terrain). For example, White (1988, Figure 6.17) compares discharge from Rock Spring (with conduit drainage) and Thompson Spring (diffuse drainage) after 250 mm of precipitation fell in 24 hours from Hurricane Agnes (June, 1972). Both springs have baseflows of about the same magnitude (about 0.2 m^3/s), but Rock Spring has a flashy response - its hydrograph peaked at a discharge over 6 m^3/s and then returned to base flow in 10-20 days. In contrast, Thompson Spring showed a rise to only about three times base flow, but discharge remained at 50% to 75% above base flow for several months.

White and Reich (1970) compared mean annual floods in small watersheds and concluded that basins underlain by clastic rocks have mean annual floods three to nine times greater per unit area than basins underlain by thick limestone. They also compared basins with conduit versus diffuse aquifers. In contrast to White's (1988) research, they found that basins with well-developed conduit aquifers had a greater capacity to quickly store water than do diffuse aquifers and therefore had reduced peaks in their hydrographs. Also, surface freezing in the winter increased flooding in basins in carbonate terrane.

DESCRIPTION OF SPRING-DOMINATED STREAMS

In this section we describe the spring-dominated channels we visited and compare spring-fed channels with runoff channels.

Descriptions of Spring-Dominated Channels in Idaho and Oregon

In order to more fully understand channel form and processes in spring-dominated channels, we examined such channels in two areas: eastern Idaho and southwestern Montana and in southwestern Oregon [Table 1].

Channel	Elevation m (ft)	Slope	Discharge m^3/s	Geology *	Date
Tom's Creek (ID)	1917 (6290)	00070	0.23		10/15/93
Buffalo Creek (ID)	1926 (6320)	0.0042	0.46		10/15/93
Whiskey Creek (ID)	2070 (6800)	0.041	0.12		10/16/93
Spring Creek (OR)	1280 (4200)	0000019		Tst	10/30/93
Spring Creek (OR) near headwaters	1280 (4200)	0.00033		Tst	10/30/93
Reservation Spring (OR)	1274 (4180)	0.0017		Qb	10/30/93
Brown Creek (OR)	1350 (4440)	0.00064	0.99		10/31/93
Snow Creek (OR)	1390 (4560)	00025	0.73		10/31/93

Table 1. Summary of spring-dominated channel attributes of sites visited in Oregon and Idaho. Geology is from Peterson and McIntyre (1970). [*Qb: Quaternary basalt; Tst: Tertiary lacustrine and fluviatile tuffaceous siltstones, siltstones, sandstones, ashy diatomite, basaltic tuffs and breccias, few thin lava flows.]

The sites in Idaho and Montana were visited in mid-October 1993 and the sites in Oregon were visited in late October 1993. These spring-dominated channels are listed in Table 1. The springs in eastern Idaho and southwestern Montana are located in the eastern-most part of the Snake River Plain and neighboring Middle Rocky Mountain physiographic provinces (Fenneman, 1931). Springs in southwest Oregon are located around the border of the Middle Cascades and Basin and Range physiographic provinces (Fenneman, 1931). Both areas are underlain by volcanic material. Spring-dominated channels exist in other terranes, but they are most common in areas underlain by volcanic material.

A series of measurements were made at the spring-dominated channels we visited. At most locations a cross section of the channel and adjacent valley was surveyed including water surface elevations at the banks, ground surface elevations, and flow depth (see for example Figure 1). Along the section, the sediment size in the channel was noted as was the vegetation and soil on the channel banks. The water-surface slope was measured over a length of at least several channel widths. Given the general lack of channel bars, this is a sufficiently long distance over which to get a representative slope. Bankfull levels were estimated at each site based upon the existence of a longitudinally persistent flat or nearly flat surface adjacent to the channel. If several surfaces existed near the channel, the extent of vegetation was used to identify the top edge of the active channel. Other significant observations were noted; these included the amount and orientation of organic debris (primarily logs) in the channel, elevation limits for various plants, the local drainage basin, local outcrops of rock, etc. Surface velocity was also measured, and discharge approximated, for several of these streams. Other spring-dominated streams that were investigated, but not surveyed include: Black Sands Spring, Meadow Creek and Twin Creek in Idaho, and Wood River in Oregon. We also discuss the observations of B. Pomeroy (Kootenai Forest, Montana) on the Spar Lake Springs, Montana.

Toms Creek, ID

The spring at the head of Toms Creek is located in the SW 1/4 of the SW 1/4 of Section 29, T.13N., R.44E. and is shown on the Island Park, ID, U.S.G.S. 7.5 minute series quadrangle. [See Appendix B for portions of the topographic map showing each site.] The spring is at an elevation of approximately 1917 m (6290 ft) and is set in a lodgepole pine forest. Access to the spring is from Forest Service Road (FSR) 1217, which leads to a primitive parking area next to a gate and a fence that spans Toms Creek. The spring is located 100 m upstream from the parking area at the head of the permanent channel and flows from the base of a 15 m cliff. The cliff

extends downstream, along the north bank of Toms Creek, to about the location of the parking area. Appendix C contains a picture of Toms Creek.

A small unchannelled draw extends upslope behind the spring at the head of Toms Creek. This draw may supply some surface drainage to the channel below the spring during heavy rains or during the spring snowmelt. The porous volcanic soil has a large infiltration rate that presumably minimizes surface runoff. The surface area drained by this draw is less than 1 km^2. Toms Creek is a tributary of the Buffalo River.

Immediately downstream of the spring, Toms Creek is about 6 to 7 meters wide and on the date of the survey was about 0.30 m deep; about 0.15 m below bankfull (Figure 1). The water-surface slope is approximately 0.0070 and discharge on the day of survey was estimated to be 0.23 m^3/s. The channel bed is composed of coarse sand and fine gravel. There is no coating of fines or algae on the surface grains. Presumably the grains on this surface were moved during a not too long ago flow. The channel does not contain organized bars although there are local

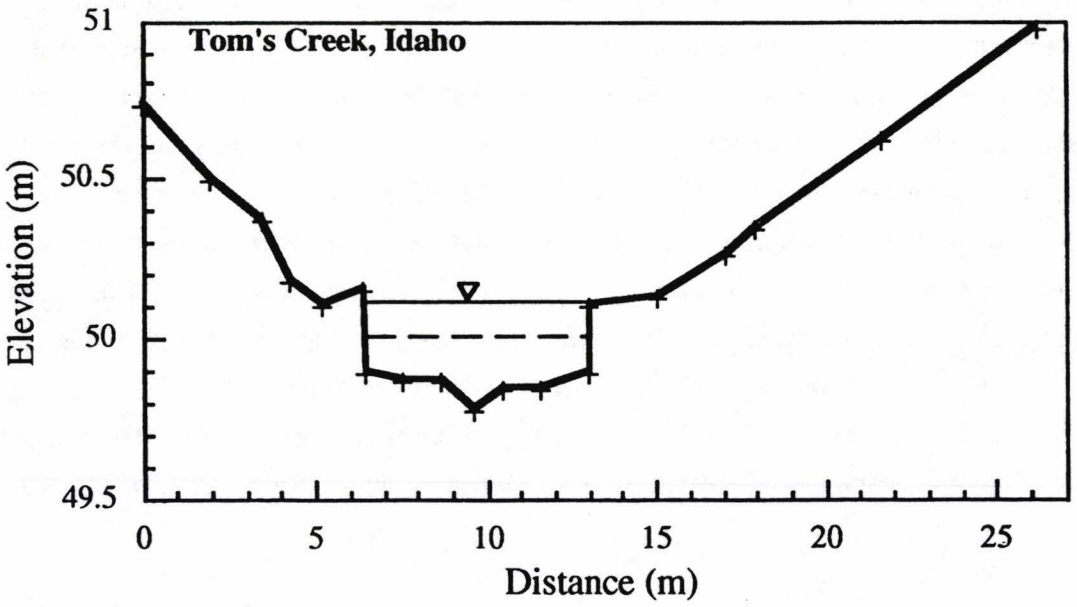

Figure 1 - Cross-section of Toms Creek. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

accumulations of sediment behind organic debris. Numerous fallen lodgepole pine logs lie spanwise in the stream. Apparently there has not been sufficient flow strength to rotate these logs to lie parallel to the bank. Various strands of flow snake around the downed trees. A single

thalweg does not appear to exist. The banks contain a substantial amount of organic material. Bank vegetation is grass and sedge. Mature lodgepole pines grow several meters back from the edge of the water, however small seedlings are found closer to the water. The stream water was clear on the day of the visit.

Buffalo River, ID

Buffalo River has several springs along its course. The spring-dominated channel discussed here is located immediately west of a primitive parking area at the end of FSR 1219, in the SW 1/4 of the SW 1/4 of Section 21, T.13.N, R.44E. The spring is shown on the Island Park, ID, U.S.G.S. 7.5 minute series quadrangle at an elevation of about 1926 m (6320 ft) [Appendix B]. The Buffalo River flows in a narrow valley bounded by 30 m (100 foot) cliffs. The Buffalo River is a tributary of the Henrys Fork. Appendix C contains a picture of the site.

The spring lies at the base of an unchanneled draw of the main valley of the Buffalo River. Surface flow through the draw cutting the rhyolite cliffs is to the mainstem of the Buffalo River and not to the spring-fed channel; at least flow is to the mainstem currently. The drainage area of this draw is less than 1 km^2. Near the point of emergence of the spring, bedrock is exposed.

The channel was surveyed about 60 m downstream of the spring and upstream of the channel's intersection with the main trunk of the Buffalo River, which has its headwaters to the northeast. The channel here is 13 m wide and 0.3 m deep (Figure 2). The slope of the water surface is 0.0042 and discharge on the date of the survey was estimated to be 0.46 m^3/s. At this discharge the channel was within a single centimeter of spilling out of its banks, at least along the left bank. At the survey location, the channel was largely filled with watercress and algae. Filaments of flow snake through the areas not choked with aquatic vegetation. The thick in-channel vegetation undoubtedly raised the stage substantially over what would have been seen during the spring, after winter cold killed the vegetation. The channel bed is composed of fine gravel with occasional cobbles. There do not appear to be bars in the channel. The banks are rich in organic material. On this low surface grow sedges and mosses. The lodgepole pines are set several meters back from the channel. Presumably, the organic rich bank near the channel is too wet for these pines. As stated earlier, the left bank of the channel was only 1 cm above the water surface. The top of right bank was about 5 cm above the water surface. This difference in height may be due to influx of sediment to the right bank from the main trunk of the Buffalo River, which shares this bank with the spring-fed channel. The main trunk of the Buffalo River

is about 6 m wide, 0.25 m deep and its banks are 0.20 to 0.25 m higher than the current water level. On the day of the visit the streamwater in both channels was very clear.

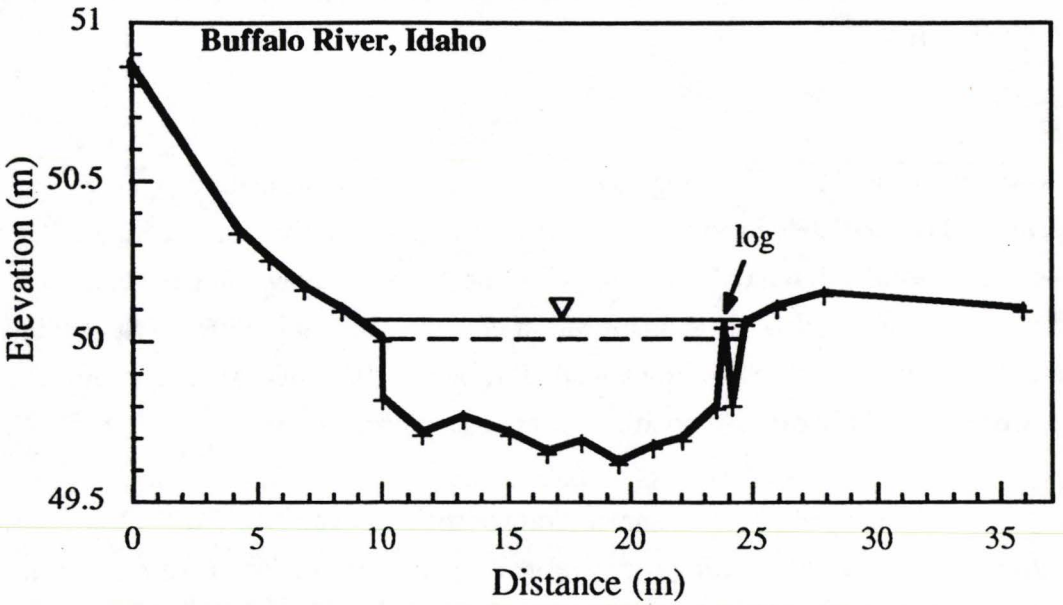

Figure 2 - Cross-section of the Buffalo River. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Big Springs, ID

Big Springs is located in the NW 1/4 of the NW 1/4 of Section 34, T.14N., R.44E. and is shown on the Big Springs, ID and Island Park, ID 7.5 minute series quadrangles [Appendix B]. The spring is at an elevation of about 1950 m (6400 ft) and is reached from FSR 059 (State Route 84) which crosses the channel. A paved parking area and camping area is located at Big Springs. The spring is set in a forest of spruce and lodgepole pine with surrounding meadows. The channel flows west into a marsh where it enters the Henrys Fork. Appendix C contains a picture of this site.

Meinzer (1923) reported that Big Springs is at the foot of a high cliff of rhyolite and spherulitic obsidian and had a flow of 5.38 m^3/s (190 ft^3/s) on June 25, 1922, 1600 m (one mile) downstream from the spring, and a flow of 5.21m^3/s (184 ft^3/s) on August 29, 1922, about 120 m (400 feet) downstream of the highway bridge next to the spring (the first measurement was made by L.L. Bryan and the second by Berkeley Johnson, both of the U.S. Geological Survey). Tourist information at Big Springs suggests that the flow is about 4.76 m^3/s (168 ft^3/s) year round.

Meinzer notes that this spring ranks among the largest in terms of discharge in the United States. Because of the large flow from this spring and the depth of the associated channel, we were not able to survey a profile of the entire channel during the reconnaissance. Rather, we chose to survey a bank profile on the right bank, about 30 m downstream of the highway bridge. Here the channel is about 50 m wide (Figure 3). At this site, there is a low bench adjacent to the channel which is about 0.1-0.2 m above the water surface. The right bank was undercut by 0.15 m. We noted a snag in a pine that had fallen in the stream that was about 0.4 m above the current water level. The upper flat surface has a very dry soil and is covered by lodgepole pine. It is certainly not a floodplain.

In contrast to previously discussed sites, there were fewer logs in the channel and most of those that were present had been rotated by the flow to parallel the banks. The channel bottom supported aquatic vegetation, with large mats visible from the highway bridge. At the survey site, the channel bed was composed of coarse sand and gravel with some aquatic grass. Upstream of the bank profile the aquatic vegetation (water cress?) formed 0.3 m thick mats which had been locally pulled up exposing the loose gravel bed. The streamwater was very clear on the day of our visit.

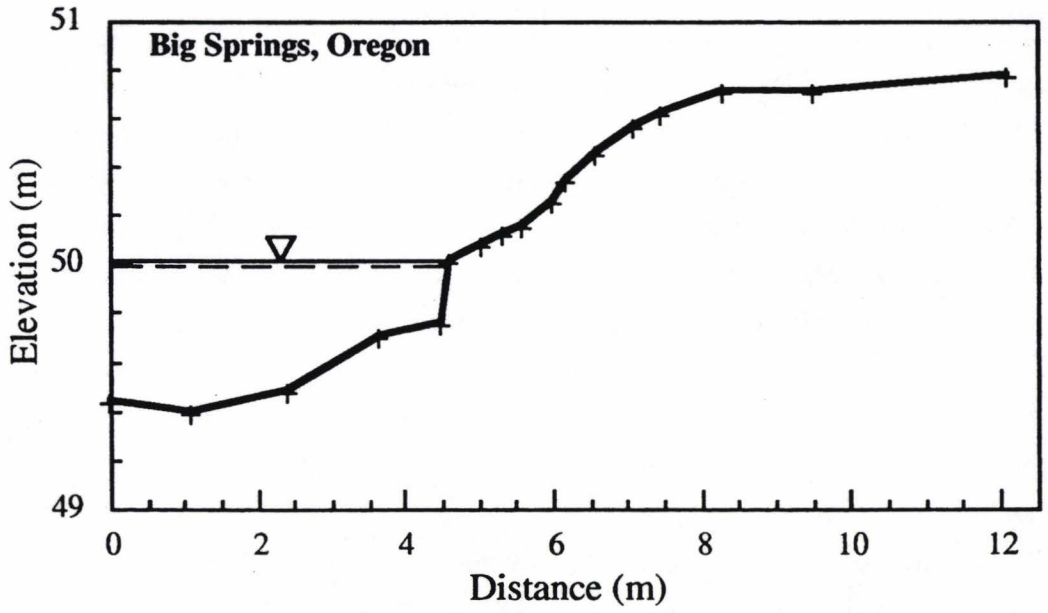

Figure 3 - Cross-section of Big Springs. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Meadow Creek Spring, ID

Meadow Creek Spring is located in the NE 1/2 of the SE 1/4 of Section 16, T.14N, R.44E at an elevation of about 1957 m (6420 ft) and is shown on the Big Springs, ID 7.5 minute series quadrangle [Appendix B]. Access to the spring is from Meadow Creek Road (FSR 060). The springs are at the base of the Henry Lake Mountains which lie to the east. In addition to Meadow Creek and its headwater spring, a number of other channels begin at springs to the northwest along the base of the mountain range - Stephens Creek, Jones Creek, Twin Creek, and Garner Springs Creek. Appendix C contains a picture of this site.

Near the head of the stream at the spring, hill slopes are bare of vegetation and worn to mineral soil, presumably by cattle. Downstream, the banks have been trodden by livestock but not as severely. In general, the channel is set in a lodgepole pine forest with trees growing on a surface that is about 0.15 m above the channel banks. The stream flows through an unforested corridor that is about 20 m wide. The banks are very rich in organic material. We presume that the soil on this low surface is so moist for most of the year that only water-tolerant plants are successful in colonizing the surface.

At about 100 m below the springs at the head of the stream, the channel is about 5 m wide and about 0.2 m deep. The bed is armored with 6 mm gravel as the median size. There is no single thalweg and the channel does not have bars. The banks are about 0.05 m above the water surface and the floodplain gently rises to about 0.1 m above the water surface 10 to 15 meters from the edge of the water. The estimated discharge on the day of the visit was about 0.28 m^3/s. Fallen trees lying crosswise in the channel are spaced about every 2 m on average. They have not been rotated by the current. The streamwater was very clear on the day of our visit. This stream was not surveyed because of the extensive disturbance of the banks by livestock.

Whiskey Creek, ID

Whiskey Creek is located southwest of the town of West Yellowstone, Montana in the Reas Pass, Idaho-Montana 7.5 minute quadrangle [Appendix B]. The elevation of the spring is near 2070 m (6800 ft). The spring exsurges through a concrete structure which is the intake for the water supply for West Yellowstone. The municipal withdrawl amounts to 0.057 m^3/s (2.0 cfs) for October through May and 0.76 m^3/s (2.7 cfs) for June through September. A baseflow of at least 0.014 m^3/s (0.5 cfs) must be maintained in the channel (Greg Widner, pers. comm.). The

hillside from which the spring exsurges has been cleared and altered by the placement of the access road. Boulders around the spring were of volcanic origin and include obsidian. A picture of the site is include in Appendix C.

The drainage area above the spring is small: certainly less than 1 km^2. The channel flows on a moderately sloped surface of lodgepole pine at the base of a 150 m (500 ft) slope. Whiskey Creek flows west to the Madison River.

The channel was studied about 100 m below the spring at the head of Whiskey Creek. The spring channel is about 3 m wide and would be about 0.35 m deep if the channel were full (Figure 4). Discharge was estimated to be about 0.12 m^3/s with the water level about 0.10 m below the top of the banks. In the summer and fall of 1986 discharge averaged about 0.20 m^3/s (7 cfs) (Interfluv report), while in the fall of 1988 during a period of drought, the discharge averaged 0.043 m^3/s (1.5 cfs) (Mark Story, memo of 11/9/88). The streamwater was very clear on the day of our visit. Fallen trees span and lie crosswise in the channel with a frequency of about one or two per meter. None of these logs have been moved by the flow. Boulders locally occurred along the bank and in the channel but the vast majority of the bed was covered by fine gravel. The water-surface slope of Whiskey Creek was 0.041. The bank material is primarily a mineral soil. Lodgepole pine grow on the sloping surface extending down to the top of the bank.

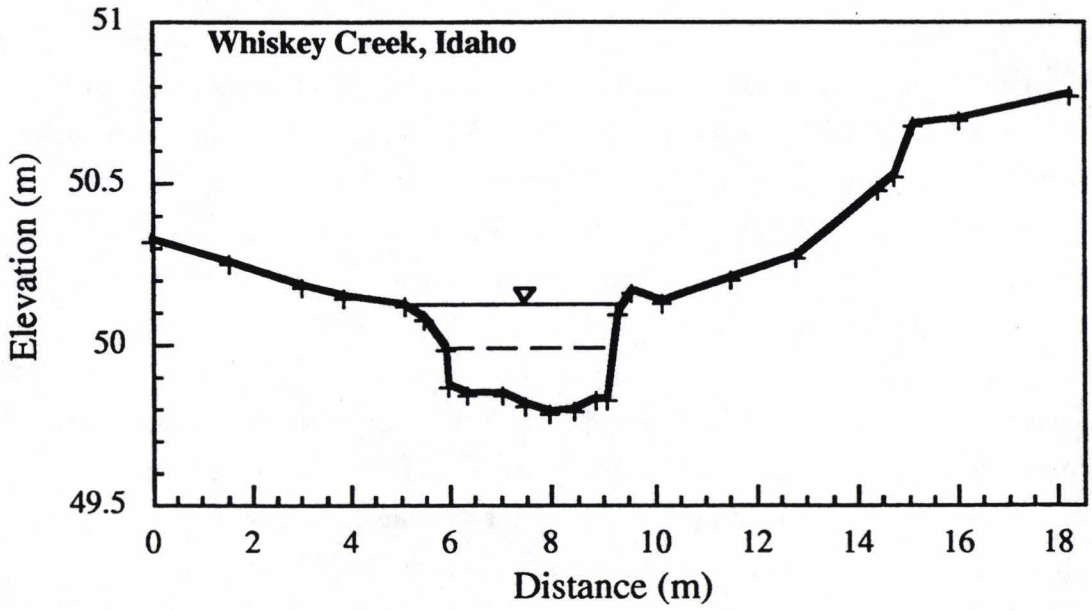

Figure 4 - Cross-section of Whiskey Creek. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Black Sand Springs, MT

Black Sand Springs is located in the SW 1/4 of the NE 1/4 of Section 31, T.54N., R.45S. and is shown on the Madison Arm 7.5 minute quadrangle. The elevation of the spring is at about 2020 m (6620 ft) [Appendix B]. Access to the spring is achieved by heading 1.3 miles west of West Yellowstone, Montana, on US Route 20/191. From there, a cinder road heads south to Black Sand Springs. The spring is set in a pine forest with pine colonizing areas down to the level of a grassy flat that was no more than 0.2 m above the water surface on the day of our visit. Trees that have fallen in the channel have not been rotated by flow.

Along the right bank there is a surface, 0.7 m above the water surface, that locally drops down to the channel-margin surface that is about 0.1 m above the water surface and up to 2 m wide. The channel below the spring is about 15 m wide with an average depth of about 0.2 - 0.25 m. The bed material is fine gravel. A single lodgepole pine has colonized an island in the channel no more than 0.20 m above the water surface. The streamwater was very clear on the day of our visit. A picture of the site can be found in Appendix C. This channel was not surveyed because of a lack of time.

Spring Creek, upper reach, OR

Spring Creek begins where a number of diffuse springs exsurge. The upper reach of Spring Creek is located in the SW 1/4 of the NE 1/4, Section 33, T.33S., R.7W and is shown on the Fort Klamath, OR, 7.5 minute series quadrangle [Appendix B]. The survey site is located about 140 m downstream of the head of the springs at the head of the creek and is at an elevation of about 1280 m (4200 ft). The site is near a picnic area at the head of the stream. Spring Creek is a tributary to the Williamson River.

The headwaters of Spring Creek lie in a re-entrant in the edge of a large volcanic plateau. One hundred meter cliffs surround the creek in all directions but to the southeast. The stream itself sits 15 meter lower in a narrow valley probably formed by headward sapping. The slopes are vegetated by lodgepole pine. Unlike many of the spring-dominated channels in their headwaters, Spring Creek has a perennial tributary that comes off of the high cliffs to the north. The area of surface drainage is approximately 15 square kilometers (6 square miles).

The channel in the headwaters is 28 m wide and about 0.65 m deep at bankfull (Figure 5). On the day of measurement, the stage was about 0.15 m below organic-rich benches next to the channel -- the surfaces interpreted to represent the top of the banks. The channel bottom is composed of sand and small gravel, with mud near the banks. The bed surface generally appears fresh; apparently the grains on the bed are moved occasionally. Logs lie crosswise in the channel about one every 10 meters. Some are covered by grasses and sedges. These vegetated tuffs grow at the level of the estimated bankfull. The channel bed lacks any bars. Christina Lillianthal (Winema National Forest) has observed rare Mare's Eggs algae in Spring Creek at this location. We also observed Mare's Eggs algae with diameters of 0.05 - 0.1 m diameter in isolated locations. The water was very clear on the day of our visit. A picture of the site can be found in Appendix C.

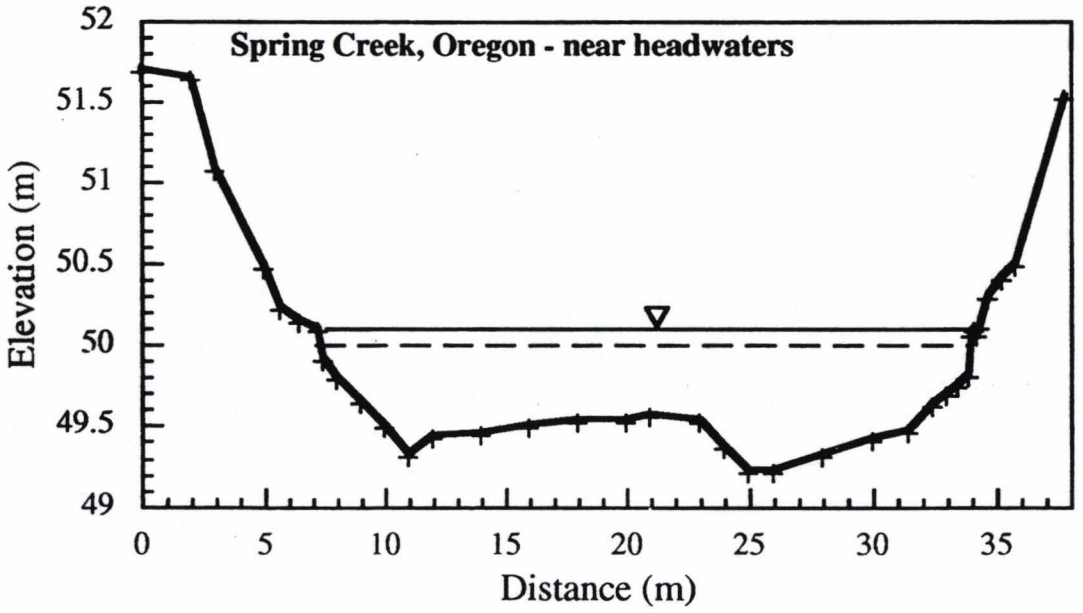

Figure 5 - Cross-section of upper Spring Creek. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Spring Creek at Collier Memorial State Park, OR

Several kilometers further downstream, in Collier Memorial State Park, Spring Creek was surveyed again. We reached the stream from the northernmost picnic area on the west side of the river in the Park. The survey site is located in the SW 1/4 of the SE 1/4, Section 4, T.34S., R.7E. and is shown on the Fort Klamath, OR, 7.5 minute series quadrangle [Appendix A]. The elevation of the creek here is about 1280 m (4200 ft).

At this point Spring Creek flows through a nearly 1.5 kilometer wide valley and the level of the channel is within a meter or so of the valley flat. The slopes and valley are covered by pine. Spring Creek enters the Williamson River about 1 kilometer downstream.

Spring Creek is about 50 m wide and is about 1.0 m deep at bankfull in the State Park (Figure 6). We measured the channel at a stage about 0.20 m below bankfull. The water surface slope is 0.000019. The channel bed is composed of mud with some sandy and gravelly areas. There are no bars within the channel. Logs and snags are scattered in the channel but the channel is wide and deep enough that they do not usually extend to the banks. The banks in along the channel are composed of less organic material than is typical of the other spring-dominated streams. The banks are fine-grained up to about the water level and then capped by grasses. The streamwater was very clear on the day of our visit. Appendix C contains a picture of the site.

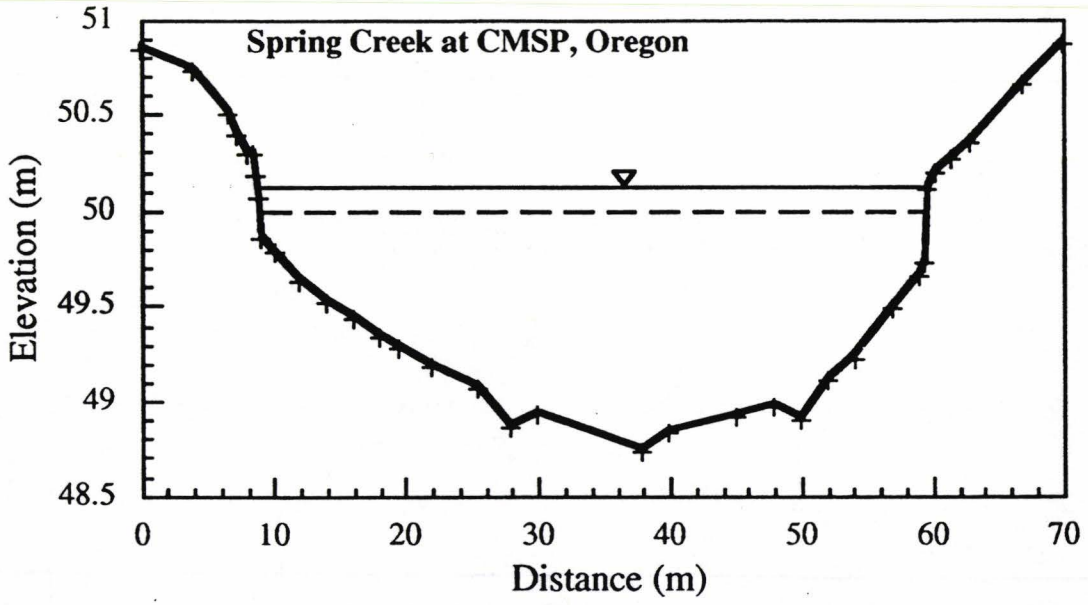

Figure 6 - Cross-section of lower Spring Creek at Collier Memorial State Park. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Wood River, OR

We examined the Wood River at the Wood River Picnic Ground. This area is shown in the SW 1/4 of Section 15, T.33S., R.7.5E of the Fort Klamath 7.5 minute quadrangle. The channel here is about 8-10 m wide and was about 0.4 m deep on the day of the reconnaissance.

Walt Lucas (Winema National Forest) estimated flow was 240 cfs during the day of our visit. Ten measurements of discharge on the Wood River ranged from 150 to 270 cfs, with low flows during times of peak diversion. We estimate the bankfull depth for this channel to be about 0.60 m. On the day of our visit, the Wood River was actively moving gravel-sized pumice. A picture of this site is included in Appendix C.

The Wood River near Fort Klamath had a gage that operated intermittently: 1918-19, 1923-36, and 1964-1967. Peak flows usually occur in the spring. The 1.5 year recurrence interval event during this period was about 340 cfs. The average discharge for the period was 215 cfs. The flow duration curve, normalized by the estimated bankfull (Eric Moser, of the Winema Nation Forest, indicated that a discharge of 274 cfs corresponds to a stage where there is a break in slope on the left bank - - this estimate of bankfull may be slightly low) is plotted in Figure 7. Some care must be taken with interpretation of these records since there were diversions for irrigation during the period of record. These diversions continue today.

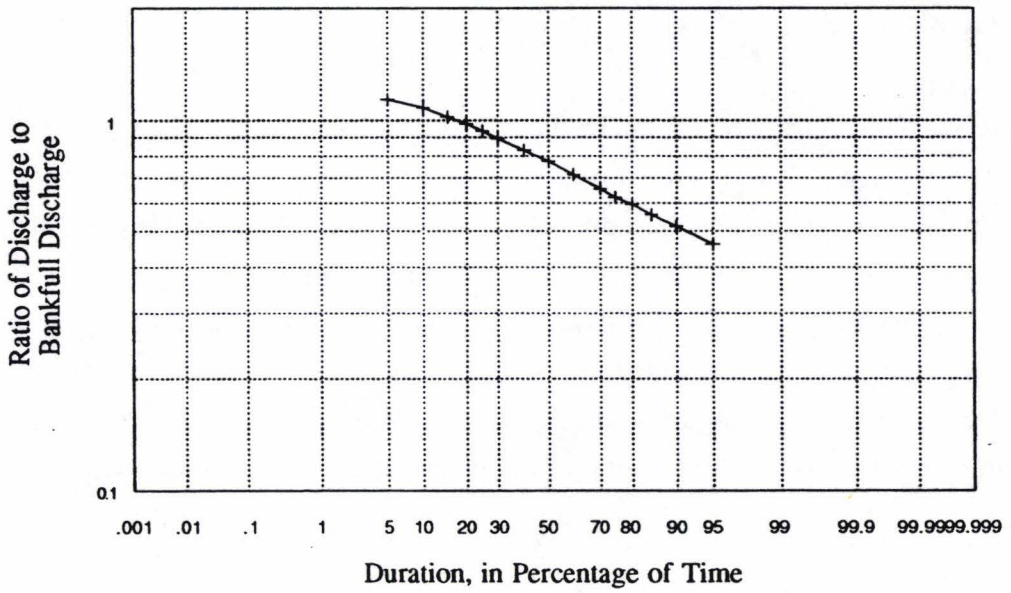
Ratio of Discharge to Bankfull Discharge
1
0.1
.001 .01 .1 1 5 10 20 30 50 70 80 90 95 99 99.9 99.9999.999
Duration, in Percentage of Time

Figure 7. The flow duration curve for Wood River at Ft. Klamath as scaled by bankfull discharge.

Because of diversion of flow in the area of the Wood River Picnic Ground, we looked for suitable sites for study near the springs at the headwater of the Wood River. The springs at the headwater of the Wood River are, in part, in Jackson F. Kimball State Park which is located in

the E1/2 of Section 3, T.33S., R.7.5E of the Fort Klamath, OR 7.5 minute quadrangle at an elevation of about 1280 m (4198 ft) [Appendix A]. The springs and channel have a "T" geometry in which the horizontal slash of the "T" would represent the headwaters and springs of the Wood River. A spring is located at each end of the crossbar. The springs emerge at the base of a steep 150 meter high (500 foot) slope that appears to be a faultline scarp. This scarp runs north northwest for many kilometers and other springs are found along it. The water in the Wood River springs is clear, deep (1-2 m), wide (50 m) and languid. There was no recognizable velocity in this area. The channel of the Wood River proper is the vertical slash of the '"T". The backwater conditions made interpretation of the channel banks difficult; banks had many characteristics of a marsh surrounding a lake, as opposed to a river-channel bank. For these reasons the site was not studied in detail.

Reservation Spring and Fort Creek, OR

Fort Creek begins at Reservation Spring. Reservation Spring is about 6 kilometers southeast of Wood River Springs. The channel was surveyed about 35 m below the emergence of the spring at a location in the NW 1/4, NE 1/4, Section 23, T.33S., R.7.5E. of the Fort Klamath, OR 7.5 minute series quadrangle [Appendix B]. The elevation of the spring is about 1274 m (4180 ft).

Reservation Spring begins at the base of a steep faultline scarp. The spring and Fort Creek lie in a very narrow valley probably created by upstream sapping of the bedrock by the spring. There is a very small, boulder covered draw that extends to the north along the trace of the steep scarp. This draw has a base that is about 5 meters above the level of the spring. The area drained by this draw is minor. Until last year, Fort Creek was impounded by an earthen dam several hundred meters below the study site. We are certain that the effects did not extend up to the study site because the strandlines of the former reservoir merge with the channel banks below the study site. The dam was breached during the winter of 1992-93. The hillslopes are covered by pine.

Fort Creek begins at the spring exsurging from a bouldery area at the head of a small valley. Boulders were generally 1 m or more in diameter and are found around the spring and up to about 10 m downstream of the spring. There were no intermediate (<1 m) boulders downstream in the channel which might have represented further breakdown and transport of these large grains. It should be noted that much of the surficial material in this canyon is pumice, which floats down the channel upon entering the spring (unless trapped, by a fallen log for

The channel flows through a broad pine-covered valley at the base of Browns Mountain. The area is underlain by volcanic material and there have been volcanic eruptions in the area in the Pleistocene. The surface area upstream of the survey site is about 45 km^2. The springs issue from the northwest side of the valley walls.

At the survey site, the channel was about 22 m wide and 0.35 m deep at bankfull (Figure 9). Along the left bank, the low surface that we interpret as the floodplain is composed largely of organic material. This surface is about 0.05 m above the level of the water at the stage measured. On the day of our visit (10/31/93), the channel the discharge was 0.99 m^3/s (35 cfs) (Mark Clark, Oregon Water Board, pers. comm.). The channel appears be eroding a terrace along the right bank thus explaining the greater elevation of this bank above the water. Further downstream, where the right bank is the inside bend of the stream, the top of the bank appears about 0.10 m lower than at the survey site. The water surface slope is 0.00064. The bed is composed of sand and gravel that is loose and free of mud or algal coatings. There are some fallen logs within the channel. The channel contains bars and channel bends appear to be migrating laterally. The channel of Browns Creek appears somewhat more like the common runoff channels. It is interesting to note that this channel has the largest drainage areas of the sites studied. The streamwater was very clear on the day of our visit. A photo of Browns Creek is included in Appendix C.

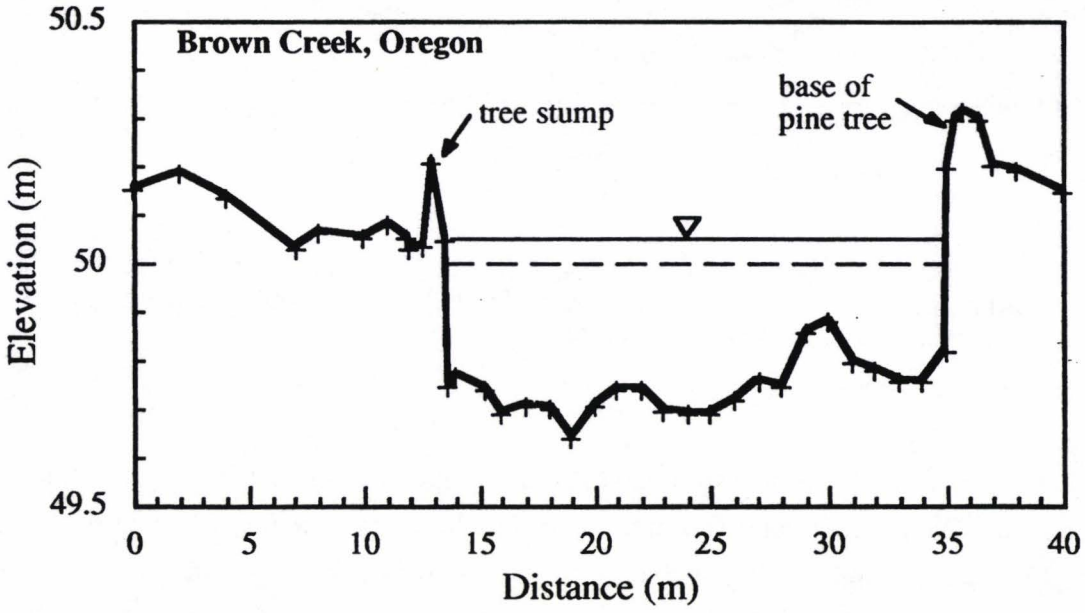

Figure 9 - Cross-section of Browns Creek. The solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

example, and saturated with water). The channel of Fort Creek is about 16 m wide and is 0.70 m deep at a stage that just fills the low banks (Figure 8). The stage was measured at a level about 0.25 m below the top of these banks. The definition of the top of the bank is subtle - a vegetative mat along the left bank ramps down toward the water surface. This mat overhangs the water by at least 0.80 m. Along the right side of the channel, the bank top is also poorly defined and the surface is narrow. The delineation of this surface as the bankfull level is supported by the growth at this level of sedge and grass on woody debris that has fallen into the channel. Numerous trees have fallen into the channel. The average distance between falls is about 5-10 m. The logs lie spanwise across the channel and have not been rotated by the flow to parallel the banks. The channel contains no bars and the flow snakes around organic debris. The streamwater was very clear on the day of our visit. A photograph of the site can be found in Appendix C.

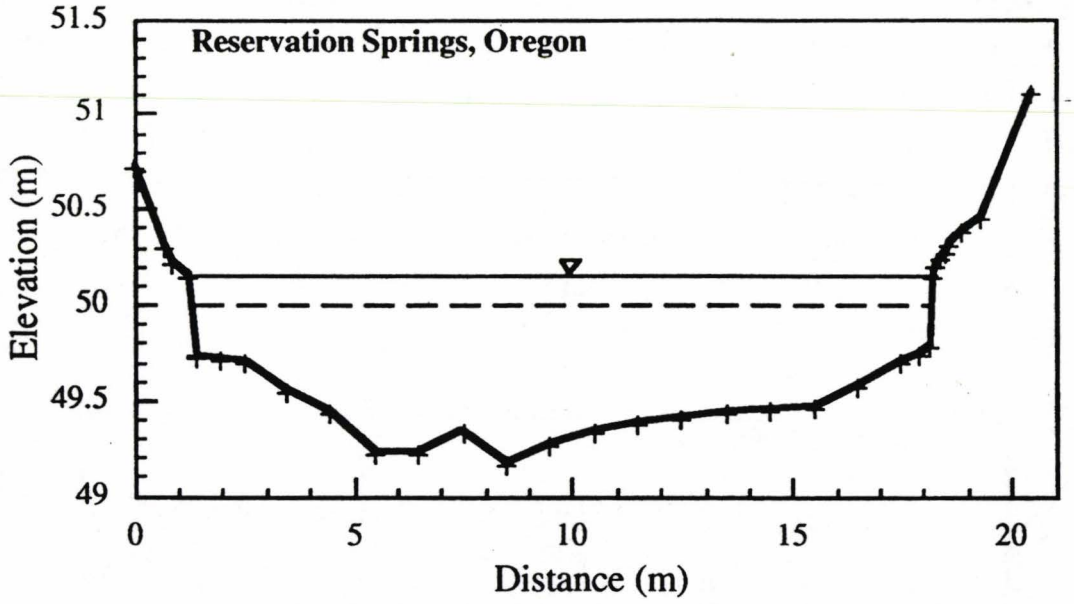

Figure 8 - Cross-section of Fort Creek. Solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Browns Creek, OR

Browns Creek is located in the SW 1/4 of the NE 1/4, Section 30, T.21S., R.8E. and is shown on the Davis Mountain 7.5 minute series quadrangle [Appendix B]. The site can be reached by turning south off FSR 880 onto a dirt road and continuing about an 0.2 kilometers. The springs are at an elevation of about 1350 m (4440 ft). A gaging station is located approximately 1 km downstream of the springs. We selected a survey site about 100 m below the springs.

Browns Creek has had a recording gage since 1939 and is one of the few gages on spring-dominated channels of which we are aware. Thus this is one site where we can examine in some detail the hydrology of the site and in particular examine the flow duration curves, the timing of flows, and the magnitude of floods. Unfortunately, bedload and suspended load measurements do not exist so we can not make calculations of the effective discharge.

Browns Creek floods in the late summer and fall (Figure 10). Forest Service hydrologists have measured the bankfull discharge as 1.36 m^3/s (48 cfs) at the gage less than a kilometer below the cross-section. The recurrance interval of flows of different magnitude is shown on Figure 11. The bankfull discharge has a recurrence interval of 1.67 years. The largest flood of record, 2.95 m^3/s (104 cfs), has a recurrence interval slightly greater than 100 years. The 100 year flood discharge is 2.86 m^3/s (101 cfs).

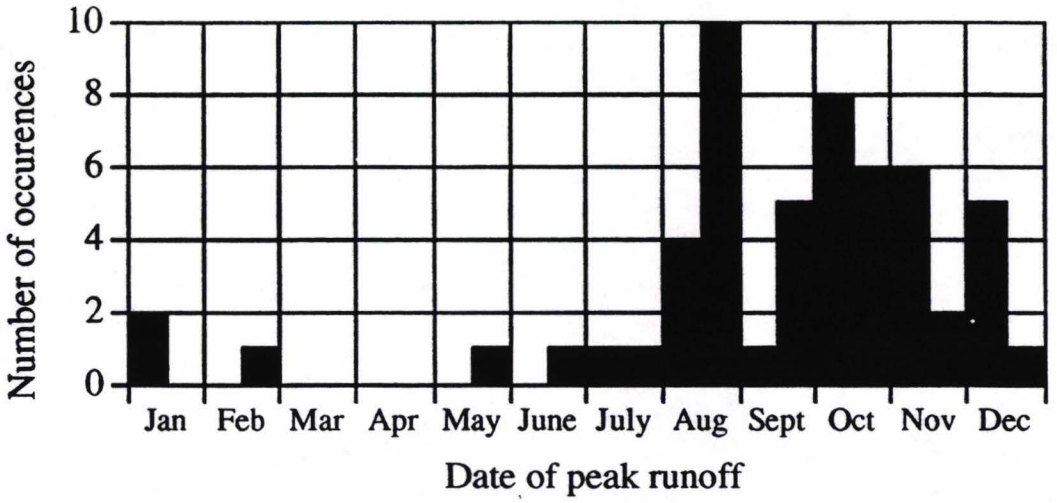

Figure 10. Annual peak flows on Browns Creek usually occur in the late summer and fall. Number of occurrences is based on 55 years of data.

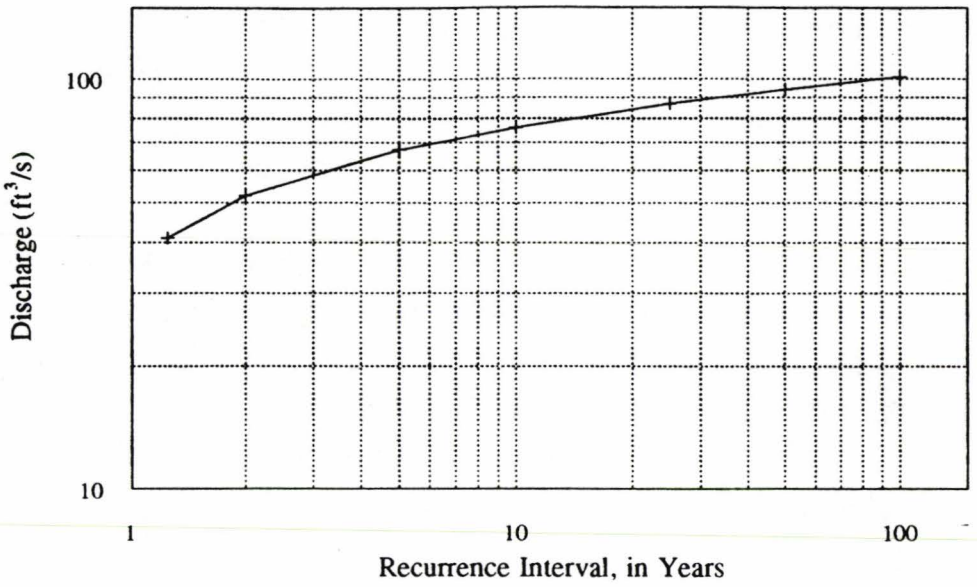

Figure 11. The flood frequency curve for Browns Creek .

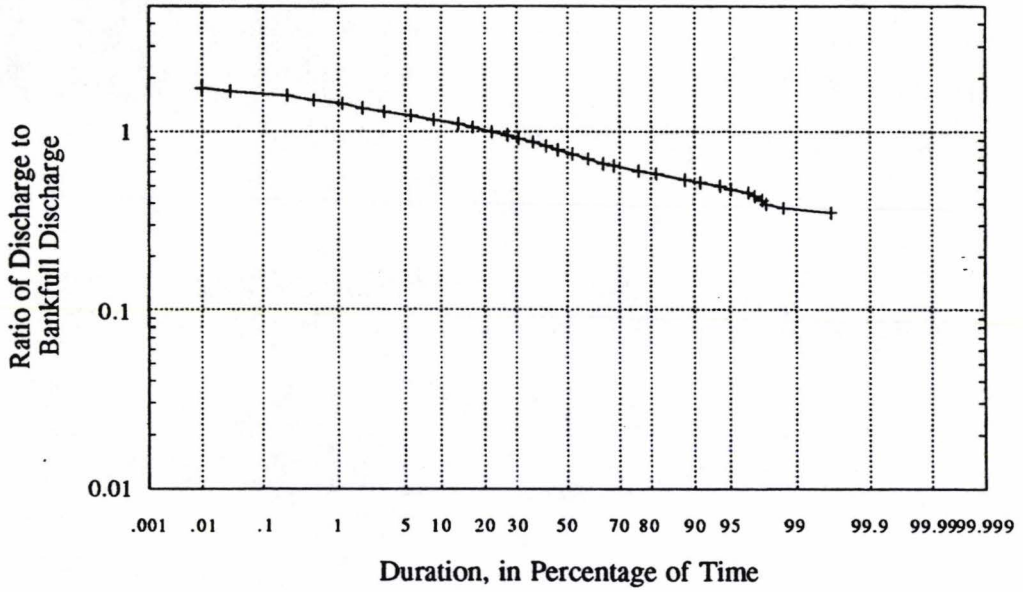
1
0.1
0.01
Ratio of Discharge to Bankfull Discharge
.001 .01 .1 1 5 10 20 30 50 70 80 90 95 99 99.9 99.99 99.999
Duration, in Percentage of Time

Figure 12. The flow duration curve for Browns Creek as scaled by bankfull discharge.

The flow duration curve for Browns Creek is shown in Figure 12. The discharge is normalized by the bankfull discharge of 1.36 m^3/s (48 cfs). The local Forest Service hydrologists report that Brown Creek does not fluctuate very much. At Browns Creek, the average annual discharge is 1.07 m^3/s (38 cfs) and the baseflow is 0.88 m^3/s (31 cfs) (Eric Moser, pers. comm.). The average annual discharge is exceeded 50 percent of the time while the baseflow is exceeded 70 percent of the time. Discharge exceeds bankfull 22 percent of the time.

Snow Creek, OR

We visited Snow Creek at its headwaters and surveyed a cross section 200 m upstream of where FSR 4270 crosses Snow Creek (SE 1/4, SE 1/4, Section 4, R.8E., T.20S.). The area is shown on the Crane Prairie Reservoir 7.5 minute quadrangle [Appendix B]. The creek runs parallel to the road and is about 10-15 m from FSR 4270 at the survey site. The survey location is about 50 m upstream of a USFS Work Site facility and is set in a pine forest which seperates the creek from the road and the facility. The elevation of the site is 1390 m (4560 ft).

The spring at the headwaters of Snow Creek is located in a narrow steep-walled valley. At the study site, the channel is flows in a substantially wider valley on a broad alluvial fan. The soils in this valley are porous and volcanic.

At the survey site, the channel is about 10 m wide and the bankfull channel depth is about 0.35 m (Figure 13). The water-surface slope is 0.0025. The channel bottom on the left side at the cross-section is a rock slab covered with some gravel. To the right of the rock, sand, gravel and some cobbles cover the bed. A narrow low bench, about 1 m wide, lies along the right bank. It is covered by mosses and grasses. The level of this vegetative mat defines the top of the channel banks. At the stage measured, this surface was about 0.10 m above the water surface. The channel gradient is controlled locally by organic steps and boulders. Rocks in the channel that protrude above the surface are covered with moss and lichen that grows to within 0.05 m of the water surface. The lowest elevation of growth of lichen has been to found to correlate with flow leveles which occur once or twice a year (Gregory, 1976). Algae is growing below the water surface on these large rocks. Elsewhere the channel bed grains are loose and free of algal or mud coatings. Above the bankfull level the ground is covered by duff and the soils are dry. The streamwater was very clear on the day of our visit. A photo of the site can be found in Appendix C.

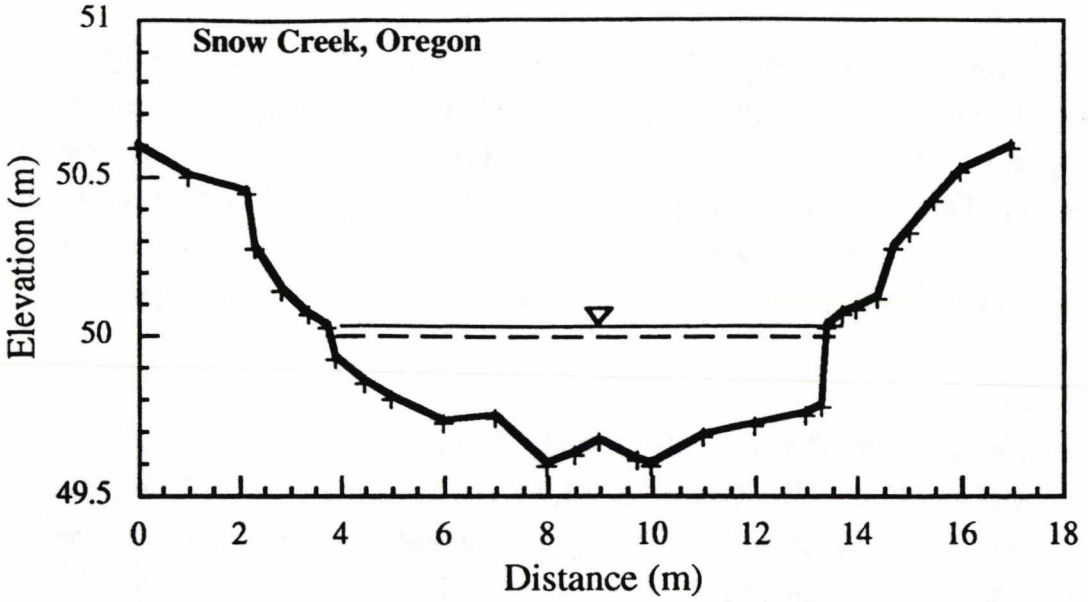

Figure 13 - Cross-section of Snow Creek. Solid heavy line is the topographic profile, the line with the inverted triangle is the bankfull level, and the dashed line is the water level on the date of the survey.

Spar Lake Springs, MT

Spar Lake Springs are located in Sections 13 and 14, T.29N., R.34E. at an elevation of about 777 m (2550 feet) on the Spar Lake, Montana 7.5 minute series quadrangle [Appendix B]. Slides of these springs and a report were sent to us by B. Pomeroy of Kootenai National Forest. Pomeroy's report indicates that the springs are recharged by Spar Lake which is dammed by a glacial moraine. The Spar Lake Springs occur about half a mile downhill of the base of the moraine in a broad valley. There is no surface outflow from the lake. Fairway Creek is the stream into which the springs discharge and the drainage area of Fairway Creek is about 8 km^2.

The slides provided show several characteristics of streams that we visited in Idaho and Oregon. For example, vegetation grows to the water's edge and numerous fallen logs lie across the channel with no evidence of their rotation by flow. Mosses cover these logs to the waters edge. Creeks emerging form the springs are about 2 meters wide. Slides also show a bench, about 3 meters wide and maybe 0.10 m above the water level, near a spring outlet. Further downstream, the flows from the various springs merge to form a channel that appears 5 to 10 meters wide with flows occasionally energetic enough to rotate logs in the channel.

Other spring-fed channels

Various other examples of spring-dominated channels exist. Poindexter Slough outside Dillon, Montana, has a large 30+ cfs spring and channel that is a major fishery (Peter Bengeyfield, pers. comm.). The Upper Verde River near Paulden, Arizona, on the Prescott National Forest is another example.

Summary of spring-dominated channel attributes

The spring-dominated channels we visited appear to be perennial streams. Topographic maps also indicate that these channels are perennial. The channels have well-defined banks composed of alluvium and organic debris. The banks rise steeply up out of the water often terminating abruptly at a nearly level surface or bench along each side of the channel - this appears to be the floodplain. In all cases the top of the bank is recognizable by a change in the slope of the bank. In most cases the surface next to the channel is at the same elevation on both sides of the channel. The exceptions appear to be associated with erosion of a terrace as the channel migrates across the valley. The lower part of the channel bank is bare alluvium. Grasses, sedges, and other water tolerant plants are common along the upper bank and on the nearly flat benches near the channel. Tufts of grass grow at and above elevation of the floodplain on logs in the channel. Pines and other less water tolerant plants are usually set back from the channel and grow slightly above the level of the floodplain. This conspicuous treeless corridor along the channel sometimes lacks even willows.

The spring-dominated channels are many times wider than they are deep. The ratio of channel width to depth is 33 for the sites studied and ranges from 9 to 63. The channels are generally rectangular in cross-section and typically lack bars. Flow snakes around downed logs in the channel. It seems common for there to be at least one piece of organic debris, spanning or nearly spanning the stream every channel width. The logs are usually lying cross-wise in the channel and have not been rotated by sufficiently strong flows to more streamwise alignments. There is usually not a well-developed thalweg. It appears that aquatic vegetation can become very extensive in these channels. This growth may be killed seasonally by cold.

The sediment in these spring-dominated channels is variable in size - they may contain gravels, sands and mud. Only in the channel at the very head of the spring are cobbles and boulders found. The sediment in the channel is loose and walking over the bed usually leaves a foot-print. This observation and the lack of fine mud or algal or other coatings on grains suggests that the bed grains have been mobile in the not too distant past - probably during the last flood. Apparently flows are energetic enough to move sediment, but not sufficiently energetic to

build bars or to carry away or rotate organic debris. In the upstream portions of these channels, there is limited availability of sediment. The reason for this impression is the lack of any channel above the spring at the channel heads and the extensive vegetation on the hillslopes and valley flat. The streamwater was very clear at each site suggesting the channel carries very little material even at these relatively high stages.

The hydrology of spring-dominated channels, if Browns Creek and Wood River are representative, is different in a number of ways from runoff streams which derive their flows from snowmelt and rainfall. Figure 14 compares flow duration curves from Browns Creek and Wood River to the characteristic curves from the upper Salmon River drainages which receive the bulk of their flows from snowmelt (Emmett, 1975). Spring-dominated streams have a

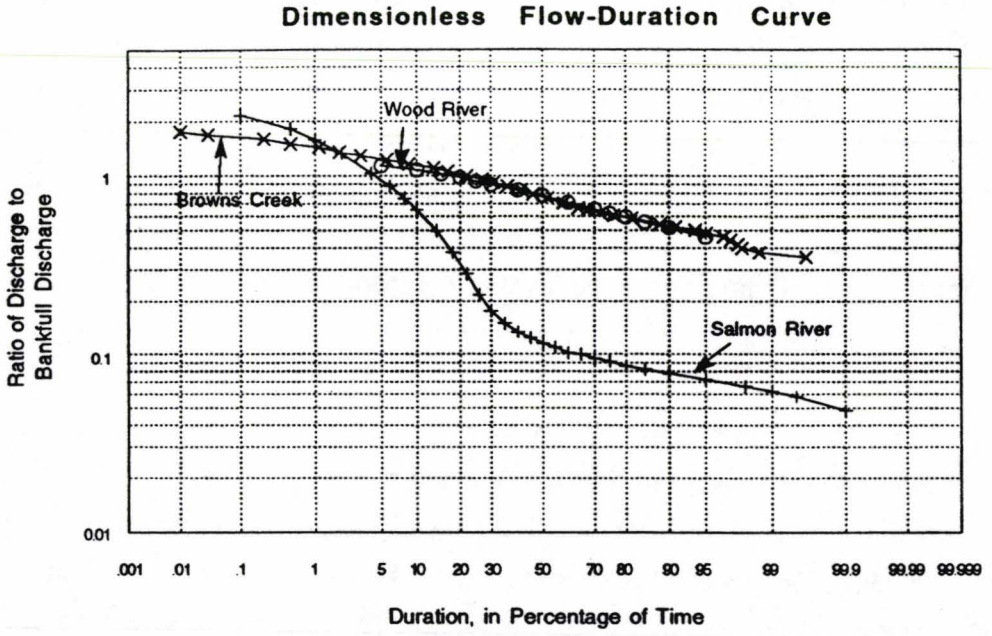

Figure 14. The flow duration curve for spring-dominated streams like Browns Creek and Wood River has far less discharge fluctuation than for runoff channels as scaled by bankfull discharge. The characteristic curve for runoff channels in the upper Salmon River drainage is from Emmett (1975).

relatively narrow range of flows. Or in other words, spring-dominated channels have discharge fluctuations that are very damped compared to the flashy runoff channels. The average annual flow on Browns Creek, normalized by the bankfull discharge, is 0.80, whereas this ratio in the Salmon River drainages is 0.25 (Emmett, 1975). In eight Wyoming streams, the ratio of average annual flow to bankfull flow is 0.14 (Dunne and Leopold, 1978). The ratio of baseflow to

bankfull flow at Browns Creek is 0.65 whereas this ratio in the Salmon River drainages is usually less than 0.10.

Bankfull discharges occur on Browns Creek with a recurrence interval of 1.67 years. This is nearly indistinguishable from the recurrence interval of 1.5 years thought to be typical of runoff streams (Wolman and Leopold, 1957; Emmett, 1975). While the frequency is similar to that of runoff channels, the timing of floods in late summer and fall is unusual (see Figure 10).

At discharges greater than bankfull, Browns Creek discharge fluctuations are damped and do not peak as high as runoff channels. Figure 15 compares the flow frequencies of Browns Creek and Wood River to the characteristic flow frequencies in the upper Salmon River drainages (Emmett, 1975). The 100-year flood on Brown's Creek has a discharge 2.1 times greater than bankfull whereas this event in the Salmon River drainages has a discharge 2.9 times greater than bankfull. For the ten-year flood, the ratios are 1.58 and 2.2. Bankfull and greater discharges occur an incredible 22 percent of the time at Browns Creek. In the Salmon River drainages the corresponding figure is 4 percent (Emmett, 1975). In eight Wyoming streams, the channel is out of its banks 2.1 percent of the time (Dunne and Leopold, 1978).

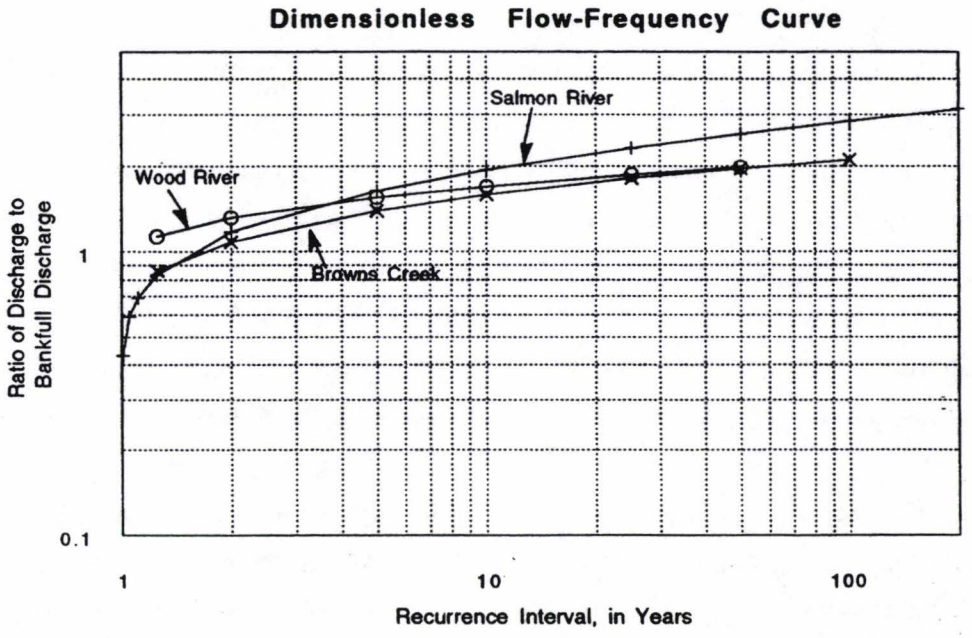

Figure 15. The floods on spring-dominated streams like Browns Creek and Wood River are not as large as floods on runoff channels as scaled by bankfull discharge. The characteristic curve for runoff channels in the upper Salmon River drainage is from Emmett (1975).

The relatively low flood peaks and relatively narrow range of discharges in these channels are probably a result of a long and possibly complicated subterranean flow path. Peak flows from springs may often occur months, or possibly even years, after recharge. For the same reasons, various discharges (bankfull, mean annual flow and baseflow) which in runoff channels are well-correlated to drainage area, are poorly-correlated in spring-dominated channels. The relatively high water level in the channel almost certainly is the reason the floodplain is so moist throughout the year. And this persistent wetness probably keeps the pines from occupying the floodplain near the channel.

There are other ways in which the hydrology of run-off and spring-dominated channels may differ, but the lack of information about spring-dominated channels makes a definitive comparison difficult. It is generally accepted that the dominant event in run-off channels, responsible for maintaining the form of the channel, is the bankfull event (Miller and Wolman, 1960; Andrews, 1980). This analysis has not been done for spring-dominated channels and the difference in the shapes of the flow frequency curves between runoff and spring-dominated channels, might be expected to alter conclusions regarding the importance of different events. The frequency of bankfull flows on spring-dominated channels has not been firmly established even though it occurs at Browns Creek with a recurrence interval of near 1.5 years.

The importance of the distinct hydrology of spring dominated channels for riparian plants is tied primarily to the persistence of wetness. These spring-dominated channels have relatively little range in flows and water levels are close to, or above, bankfull for long periods. On Browns Creek flow is above bankfull 22 % of the time (80 days a year). Water levels are high enough to keep the floodplain soils moist for much longer periods of time. Plants colonizing the floodplain must be tolerant of extended periods of saturation and inundation and have long hydroperiods. There is little doubt that this explains the well-defined corridor without pines along the channel. The reason willows and similar plants do not grow in these areas is unknown.

The peak flows in many streams visited occurred in late summer and fall. It is unknown whether this may be important to plant physiology occuring as it does during periods of major plant productivity. In spring-dominated channels, overbank discharges are not as great as in runoff channels and this may reduce riparian disturbance by large flows.

APPLICATION OF CHANNEL MAINTENANCE METHODS TO SPRING-DOMINATED STREAMS

In this section we will discuss in more detail current channel maintenance methods and their application to spring-dominated channels.

Review of Channel Maintenance Methods for Alluvial Channels

Channel maintenance procedures are applied to calculate the non-consumptive, in-channel flows required to maintain favorable water flows as mandated by the Organic Administration Act [Act of June 4, 1897 (16 U.S.C. 475)]. The flows are designed primarily to maintain the channel's capacity to pass floods, but the instream flow have the indirect benefit of preserving aquatic habitat. The method is applicable to watersheds where flow is perennial and dominated by runoff from snowmelt. Furthermore the method is designed for channels that are free to adjust their geometry and/or gradient in response to alterations in the streamflow.

The methodology is predicated upon a number of underlying scientific principles in geomorphology and hydrology. These are discussed below. An alluvial channel is dynamically adjusted to the amount of water and sediment that it receives. There is a discharge that over time is the most important in forming the channel - the so called 'effective' or 'dominant' discharge (Wolman and Miller, 1960; Andrews, 1980). This is generally equivalent to the discharge that fills the bank. This bankfull discharge has a recurrence interval of 1 to 5 years and is reasonably estimated by those discharges with a recurrence interval of 1.5 years (Wolman and Leopold, 1957). Flows larger than bankfull are not important in maintaining channel capacity to pass floods. Despite the great importance of bankfull flows, baseflow and intermediate flows also play roles in maintaining the channel. These flows act to move fine sediment, prevent the encroachment of vegetation, and keep the substrate from becoming cemented. These flows also provide the indirect benefit of preserving aquatic habitat. There are compensatory changes in channel depth, sediment discharge and/or slope that result from the alteration in flow discharge. In general, the amount of sediment delivered from tributaries is not significantly affected by changes in mainstem flow discharge - this is one of the most important consequences of flow modification. A failure to maintain the channel's capacity to pass flows results in channel changes that are unfavorable. Approximate maintenance of the channel can be realized through a range of discharges that include rise, bankfull, recession and baseflow components.

The application of the methodology often requires that information from gaged sites be extrapolated to ungaged sites because of the limited availability of information and resources. Consequently it is assumed that maintenance flows at ungaged sites can be determined by methods other than direct measurement of discharge. Among the ways to develop relationships that can be transferred to other sites is hydraulic geometry. Hydraulic geometry (Leopold and Maddock, 1953) relates the characteristics and dimensions of the channel (width, depth, and velocity) to the discharge and particularly to the bankfull discharge. Channel width is thought to be most consistent predictor of a channel's bankfull discharge. Drainage area is also thought to be well correlated to width and therefore width or even drainage area can be used to estimate bankfull discharges. Similarly the discharge with a recurrence interval of 1.5 years can be transferred to ungaged sites by relating the discharge to drainage area.

The flows required for alluvial channel maintenance are divided into three parts: bankfull, rise-recession and baseflow. An overview of how these flows are computed, as described in Chapter 30, is given here. The first step of the procedure is to plot a flow-duration curve ('discharge' vs. 'time equaled or exceeded') using gaging-station data from the stream of interests or from gages at other representative or suitable streams. This curve is normalized to bankfull discharge. The required duration of bankfull flow is the amount of time where normalized discharge of 1.0 is equaled or exceeded. Required duration of discharges that are less than bankfull but greater than mean-annual discharge are the rise-recession flows. This is determined in a stepwise manner. The normalized discharge is decreased by increments of 0.1 from 1.0 (bankfull) to that fraction which represents normalized mean-annual discharge. The time required for each step is then decreased by one-half to produce the rise-recession duration. Baseflow is determined as the duration of time that the thalweg is filled minus the duration of time for the lowest discharge of the rise-recession flow. It is usually recognizable by an inflection in the flow frequency plots.

This general approach remains valid but a slight modification to the overall methodology has been introduced recently (John Potyondy, pers. comm.). The claimed flow for maintenance is all discharge less than baseflow. Baseflow discharge is claimed at flows less than average annual flow. At discharges between average annual and bankfull flow, baseflow plus a sliding percentage of the discharge exceeding average annual flow up to bankfull flow is claimed. At discharges above bankfull, bankfull discharge is claimed. The sliding percentage claimed for discharges between average annual flow and bankfull flow is

$$Q_i + \left[(Q_s - Q_i) \frac{Q_s - Q_a}{Q_b - Q_a} \right]$$

where Q_S is the stream flow, Q_i is the baseflow, Q_a is the average annual flow, and Q_b is the bankfull flow.

Discussion of the Appropriateness of the Application of Current Channel Maintenance Methods to Spring-dominated Channels

The current formulation of the channel maintenance methods for alluvial channels is not appropriate for direct application to spring-dominated channels. The reasons for this are summarized below. In Appendix A, the various problems and concerns with the application of Chapter 30 to spring-dominated channels are annotated in detail.

Chapter 30 cannot be applied directly to spring-dominated channels for the following reasons:

1) spring-dominated channels do not receive their major flows directly from the snowmelt,
2) it has not been shown that bankfull flows are the effective discharge,
3) it has not been shown that bankfull flows occur with a recurrence interval of about 1.5 years nor can this time interval be used as a surrogate for bankfull flows to estimate effective discharges,
4) extrapolation from gaged to ungaged points of quantification based upon drainage area will not work, and
5) various issues related to specific details of the methodology are inappropriate.

First, spring-dominated channels do not receive their major flows directly from the snowmelt. Springs in this report were generally in unchannelled draws which receive minor amounts of surface runoff. Chapter 30, on the other hand, was developed explicitly for snowmelt channels. While channels receiving their water from rainfall, or as in this case, springs, share many characteristics and processes, there are some actual and potential differences in form and process that must be addressed before using Chapter 30 or a cousin of Chapter 30 in hydrologic regimes other than snow-melt dominated. The differences include a flashier hydrograph in runoff channels than in spring-dominated channels.

Second, it has not been shown that bankfull flows are the effective discharge in spring-dominated channels. The entire scientific case for the importance of maintenance flows is based upon the concept that there is some most important discharge that effectively maintains the channel form and function. We found that channels below springs were nearly at bankfull during the dry autumn season. This suggests there is relatively minor fluctuation in discharge. An effective discharge may not be very distinct. In runoff channels, this effective discharge is equivalent in discharge with bankfull flows. Without the documentary information and calculations that first, spring-dominated channels are maintained by a identifiable flow, and second that this flow is approximately that of bankfull flows, the methodology does not stand up to scientific and legal scrutiny.

Third, it has not been shown conclusively that bankfull flows occur with a recurrence interval of about 1.5 years. The current formulation of Chapter 30 depends in part upon the rule-of-thumb that the bankfull flow has a recurrence interval of about 1.5 years, and so the effective discharge (equal to the bankfull flow) can be estimated by the flood with a recurrence interval of 1.5 years. The record at Browns Creek suggests that bankfull flows at that site occur with a recurrence interval of 1.67 years; for all practical purposes a value equivalent to 1.5 years. While it may be true most spring dominated channels also have such a recurrence interval of channel filling flows, this must be shown.

Fourth, extrapolation from gaged to ungaged points of quantification based upon surface drainage area may potentially give grossly inaccurate results. In spring-dominated channels, the surface drainage area bears little relation to the area contributing groundwater to the springs. In such terrains with extensive springs, much of the subterranean flow is across surface water drainage divides. The problem is most obvious at the head of such channels where there may be hardly any drainage basin upstream of a voluminous spring [See Appendix B for topographic maps on the area around the head of the channel.]. As the watershed size increases, such extrapolation methods may be more accurate.

Fifth, there are various issues related to specific details of the methodology that need to be examined and possibly modified. Among these include the determination of baseflow from the inflection on the flow frequency curves. It is not clear that such an inflection is present in spring-dominated streams. This inflection is often difficult to discern in rainfall dominated regions. If baseflow is determined by field measurement, the lack of a well-defined thalweg is

problematic. Other issues of concern may include the elevation of perennial vegetation and its use as a marker of bankfull.

RECOMMENDATIONS

On the basis of the reconnaissance and a consideration of existing methods to address channel maintenance, we see several alternatives. These are listed below.

1) Do not make channel maintenance claims in these spring-dominated streams.

2) Apply the overall concept of maintenance flows embodied by Chapter 30 to spring-dominated streams on a case by case basis. When necessary, install at each site a recording flow gage. Generate a record of flow frequency and collect bedload measurements so as to be able to calculate effective discharges. Over time, the information from each of these studies can be used to build a general body of literature in support of a method specifically applicable to spring-dominated channels.

3) Retain the overall methodology embodied as Chapter 30, but carefully investigate the particular concerns raised in this preliminary study. Conduct directed research on the specific questions of effective or dominant discharges in these channels, the frequency of overbank flooding, and the various ways to extrapolate from gaged sites to ungaged sites.

4) Initiate a general research program to study these channels and their distinct properties in order to formulate a new approach to maintaining these special channels. Investigate the channel form in spring-dominated streams, the typical amounts of sediment moved, when moved and by what style (bedload and suspended load), sediment supply from the sideslopes, bar development, the evolution of channels, flow variability, flood frequency, baseflow and average annual flow and their relation to area, and the importance of vegetation. We also suggest that effects of spring discharge on downstream channels which receive significant discharge as surface runoff be investigated, as springs may have an important impact on that aspect of channel form and process controlled by baseflow.

The various options span a great range of effort. As we see it, there are the following advantages and disadvantages to each of these alternatives. The first alternative, that of not making channel maintenance claims in such channels, might be justified by the fact there are relatively few spring-dominated streams where channel maintenance is an issue. At these sites the Forests might use other claims (fisheries, fire fighting, etc.) to prevent significant degradation of the channel. This approach has the benefit of requiring little effort in the short-term, but could mean that the Forests are ill-prepared if and when spring-dominated stream discharge becomes an issue. Also, while there may be few spring-dominated streams, flow from these streams be important contributions to streams into which they merge.

The second alternative, that of applying the general concept and methodologies of channel maintenance to spring-dominated sites on a case by case basis, has some merit. Several of the more problematic aspects of the transfer of the methodology to the different streams can be avoided if data is not extrapolated from gaged sites to ungaged sites of quantification. The major concern that is avoided is the poor correlation of discharge to surface drainage area. One might still try to use the correlation of channel width to bankfull discharge to extrapolate.

The third alternative, that of retaining the overall channel maintenance methodology embodied as Chapter 30, but carefully investigating the particular concerns raised in this preliminary study is probably the most reasonable course of action. Focused research effort on the specific concerns with the current method as applied to spring-dominated channels would prepare the Forests to better manage the resources and put the Forest Service in a better position to scientifically defend the method.

The fourth alternative, that of initiating a general research program toward understanding the hydrology, geomorphology, and ecology of spring dominated channels is the ideal approach but it may be unrealistic in terms of cost. While it is clear that there is much to be learned about such channels it may be more useful and timely to focus the research on the specific questions raised by this analysis.

We can see a limited research program along the lines of third alternative. The areas of greatest concern with the application of the current methods could be tested explicitly at several spring-dominated channels. These issues include the magnitude of the effective discharge, the magnitude of the bankfull discharge, the recurrence interval of bankfull discharges, and the equivalence of bankfull and effective discharges. This would require the existence or installation of a gage at some sites and the investment of time in measuring bedload and suspended loads.

Several sites seem particularly attractive for such studies. Browns Creek in Oregon has been gaged for many years and provides one of the few long records in such streams. The site is a little different from many other spring-dominated channels in that it has a reasonably large surface drainage area. The Buffalo River in Idaho is another attractive site because springs enter continuously along the channel thus providing the opportunity to examine the importance of the relatively broad hydrographs at various points along a drainage network. In terms of focusing on a channel receiving nearly all its water from springs, Toms Creek may be a good candidate for a study. Toms Creek is also relatively unaffected by landuse and seems in a fairly natural condition.

SUMMARY

In many respects the form and inferred hydrology of spring-dominated channels are similar to that of runoff-dominated channels. The major differences between runoff and spring-dominated channels are associated with the relative importance of the groundwater input and the consequence this may have on the form. The spring-dominated channels have a very broad flood hydrograph compared to the flashy hydrograph typical of streams receiving their flows directly from snowmelt or rainfall. Channel bars are commonly lacking in the spring-dominated streams and this may be a result of the relatively minor range of flows. There remains much that is unknown about the hydrology of the spring-dominated channels; the magnitude of effective events, the recurrence interval of bankfull discharges, and the correspondence between the two. The observable differences between runoff-dominated and spring-dominated channels and the lack of detailed understanding of the hydrology of spring-dominated channels requires that current methods for estimating channel maintenance flows be used with discretion. In general, the conceptual approach manifest as Chapter 30 seems potentially appropriate if applied to spring-dominated channels, however several scientific assumptions that are valid in alluvial channels have not been shown to be valid in spring-dominated streams, and several specific steps in the method have been shown in fact to be invalid when applied to spring-dominated channels.

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Appendix A - Annotated analysis of the Procedure for Quantifying Channel Maintenance Flows

In this appendix, Chapter 30 - Procedure for quantifying channel maintenance flows of the Water Information Management System Handbook (1987), will be examined line by line noting sections in which the application of the method to spring-fed channels may be problematic. The wording of the chapter is presented in italics to differentiate it from our comments.

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31.11 *"At present the procedure can only be applied to watersheds where streamflow is perennial and dominated by snowmelt runoff."*

The streamflow in these channels is dominated by flow from springs and the timing and magnitude of discharge may be poorly correlated to snowmelt.

31.2 6. *"The effective discharge is approximately equivalent to the discharge which occurs at bankfull stage."*

It has not been shown that the effective discharge is equivalent to bankfull flow in such channels.

31.2 7. *"Bankfull discharge is frequently occurring and can be characterized by the flow with a recurrence interval of 1 to 5 years and reasonably estimated using the flow associated with a 1.5 years recurrence interval."*

It has not been shown that the bankfull discharge by a 1 to 5 year recurrence interval event in such channels.

"The procedure does not preclude the use of a different return interval if there are reasonable and substantial grounds for the selection."

This alternative recurrence interval would have to be established by detailed studies.

31.2 13. *"Maintenance flows in ungaged watersheds can be determined through methods other than direct discharge measurement."*

This is unlikely given the incompleteness of our understanding. Particularly problematic is the fact that these methods rely on the drainage area of the watershed. For spring-fed streams the surface area of drainage may be a poor predictor of discharge.

31.2 14. *"Gaged station flow duration curves can be extrapolated to nearby, similar ungaged watersheds."*

Extrapolation is often based on the drainage area of the watershed. For spring-fed streams the surface area of drainage may be a poor predictor of discharge.

31.32 *" Caution must be exercised if the USDI Geological Survey basin-characteristics method is being used rather than a locally developed relation."*

This method should not be used since it relies on surface drainage area which will be a very poor predictor of discharge in spring-fed streams.

32. *"Use gaging station data and the appropriate application of statistical techniques to develop basic relationships that can be extrapolated to ungaged watersheds."*

Extrapolation will not work in spring fed channels and dominantly spring fed channels because basin area and elevation will be very poor indicators of channel discharge.

32.1 *"Use one of the fine analysis methods described here. "*

Several of the methods will be inappropriate. Method C cannot be used because depends upon drainage area to extrapolate data. Method D cannot be used because it depends upon using drainage area or other characteristics to calculate Pearson type III peak flow equivalent to bankfull. There will be more discussion later.

32.3 Method A Step 1 *Secure ..."Stage discharge relation....roughness"*

We noted that aquatic vegetation often fills these streams and may alter the stage discharge relation seasonally as well as the roughness.

32.3 Method A Step 2 *"Baseflow stage is the water surface elevation associated with the discharge that just fills the thalweg or inner berm"*

There is no inner berm and there are multiple thalwegs in spring-dominated channels.

32.3 Method A Step 5 *"The Manning equation may be employed to calculate bankfull discharge."*

The aquatic vegetation may complicate the use of the Manning equation.

32.4 Method B. Step 1 *Secure ..."Stage vs. discharge relations."*

We noted that aquatic vegetation often fills these streams and may alter the stage discharge relation seasonally.

32.4 Method B Step 2 *"Baseflow stage is the water surface elevation associated with the discharge that just fills the thalweg or inner berm"*

There is no inner berm and there are multiple thalwegs in spring-dominated channels.

32.4 Method B Step 4 *"... water stage vs. discharge .. calculate or measure bankfull discharge"*

As stated earlier aquatic vegetation can make this difficult.

32.5 Method C *"Use this method in those situations where the points of quantification cannot be visited to measure either the cross-sectional area and slope or bankfull width. While drainage area and ...[can be used to extrapolate data]"*

Drainage area is likely to be a poor surrogate for extrapolating data on expected discharges since the subsurface drainage area supplying the flow may not be equivalent to the surface drainage area.

32.5 Method C Step 1 *Secure ..."Stage vs. discharge relations"*

We noted that aquatic vegetation often fills these streams and may alter the stage discharge relation seasonally.

32.5 Method C Step 1 *Secure ..."Drainage area of watershed above gage."*

Drainage area is a poor surrogate for discharge in these systems.

32.5 Method C Step 2 *"Baseflow stage is the water surface elevation associated with the discharge that just fills the thalweg or inner berm"*

There is no inner berm and there are multiple thalwegs in spring-dominated channels.

32.5 Method C Step 5 *"...regress bankfull width against drainage area..."*

Drainage area is a poor surrogate for discharge in these systems.

2.5 Method C Step 7 *"Calculate drainage area ... for regression with bankfull width. "*

Drainage area is a poor surrogate for discharge in these systems.

2.6 Method D *"The method utilizes the relationship between bankfull discharge and its recurrence interval."*

The recurrence interval of bankfull flows in such channels has not been established.

2.6 Method D Step 1 *Secure ..."Drainage area of watershed above gage."*

Drainage area is a poor surrogate for discharge in these systems.

2.6 Method D Step 1 *Secure ..."Log Pearson type III 1.5 years return interval peak flow..."*

The recurrence interval of bankfull and effective flows in these channels is not known.

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2.6 Method D Step 2 *Regress the log Pearson type III 1.5 years return interval discharge against drainage area...."*

The problems associated with the lack of information on the important flows are being compounded by using drainage area to analyze the data.

2.6 Method D Step 3 *"Calculate the drainage area... for ungaged points of quantification."*

The drainage area of ungaged watersheds is likely to be a poor predictor for all the reasons given earlier.

2.6 Method D Step 4 *"Calculate the bankfull discharge for ungaged points of quantification."*

The drainage area of ungaged watersheds is likely to be a poor predictor for all the reasons given earlier.

2.7 Method E Step 1 *Secure ..."Drainage area of watershed above gage."*

Drainage area is a poor surrogate for discharge in these systems.

2.7 Method E Step 5 *"...regress bankfull discharge values... against drainage area..."*

Drainage area is a poor surrogate for discharge in these systems.

2.7 Method E Step 6 *"Calculate the bankfull discharge for ungaged points of quantification."*

The drainage area of ungaged watersheds is likely to be a poor predictor for all the reasons given earlier.

32.8 Common step 2 *"Most sediment transport will occur during the period of flow which begins with the occurrence of mean annual flow discharge and continues through bankfull discharge.*

This is probably true but should be tested.

32.8 Common step 4 *"Using local data and professional judgment determine if additional flows are needed to prevent vegetative encroachment. .... Base this upon the following .... the water storage capacity of stream side substrate."*

The streamside soils are usually very high in organic material and hold moisture well.

32.8 Common step 8 *"Normalize and display the representative hydrographs."*

The hydrographs for spring-dominated channels can be expected to be far less peaked than alluvial channels.

32.8 Common step 9 *"Identify .... the start of the snowmelt season"*

The flows in these basins are not directly linked to the snowmelt. In any case this step dates to an older version of the method for triggering the channel maintenance claims. The current dynamic- hydrograph approach is still explicitly for snowmelt.

36.2 Appendix B *"Determination of the 1.5 Year Peak Flow Rate"*

It has not been established that this is the formative flow in these channels.

36.3 Appendix C *"To estimate bankfull discharge on ungaged water sheds, channel characteristics such as channel cross-sectional area and water surface slope can be related to gaged records, 1.5 years return interval flows, or the Williams regression equation."*

The fact that it is premature to suggest that channel maintenance flows for spring-dominated channels is equivalent to that for alluvial channels is premature. The regression equation should only be used in limited situations and a new regression should be derived if it is to be applied to spring-dominated channels.

36.3 Appendix C - Limitations *"Do not use the channel -geometry method on stream reaches with the following characteristics - ... braided channel reaches."*

The spring fed channels are for the most part single strand. However in most cases the flow is multistrand. There is typically no single thalweg.

36.4 Appendix D - Concepts Used in the Procedure *"The existing form and characteristics of rivers, streams and creeks have developed in a predictable manner as a result of the water and sediment load imposed from upstream."*

We simply note that in some cases the upstream supply of sediment is very minor. The streams begin at a particular location and little if any sediment is available.

36.4 Appendix D - Concepts Used in the Procedure *"Their shape and size develop in a manner consistent with their drainage basin's character and area."*

The flow in spring-dominated channels comes largely from deep groundwater flow. There is often a poor correspondence between the surface area that drains to some point along a spring fed channel and the amount of flow in the channel. Often the hydrograph of the springs rises and falls with little connection to precipitation and the total discharge is far too large to have come from the surface drainage area. The deeper groundwater systems that feed the springs often have a substantially larger watershed.

36.41 Appendix D - Concepts - Hydraulic Geometry-Discharge Relationships *"The United States Department of the Interior Geological Survey has tested the relationships of mean annual discharge to width and depth in meandering channels ....and have been found to be consistent enough to be used by engineers to predict discharge on ungaged streams over widespread areas."*

In spring-dominated channels it is not clear that mean annual flow will be well correlated to the channel dimensions - this could be examined. In addition, these channels are not meandering.

36.41 Appendix D - Concepts - Hydraulic Geometry-Discharge Relationships *"It has also been observed that bankfull width is consistently correlated with flow. ... Thus, the bankfull width of individual stream reaches can be used to estimate flow parameters having specific recurrence intervals."*

The recurrence intervals bankfull flows in these channels has not been established. One cannot make the assumption that width will be related to any specific recurrence interval.

36.42 Appendix D - Concepts - Effective or Dominant Discharge *"The magnitude of the effective or dominant discharge was examined by Andrews who concluded that it was nearly equal to the discharge at bankfull stage."*

In spring-dominated channels this must be shown before the method is applied. It may be that the effective discharge is the bankfull flow, but given the far different flow frequency curve of these spring-dominated channels compared to alluvial channels, the question should be examined.

36.42 Appendix D - Concepts - Effective or Dominant Discharge *"The frequency of the effective or dominant discharge has been studied by several researchers in both snow and rainfall dominated areas. Andrews found that the recurrence interval in the Yampa basin... is between 1.18 and 1.4 years."*

In spring-dominated channels this must be shown before the method is applied. At least a number of sites should be studied to ascertain the frequency of effective events.

36.43 Appendix D - Concepts - Sediment Transport-Discharge Relationships *"The thalweg channel appears to be an integral characteristic of stable channel systems and is generally apparent and measurable in alluvial channels. The sediment transport which occurs during baseflow discharge helps maintain the capacity of the thalweg channel."*

The flow in these channels is multistrand.

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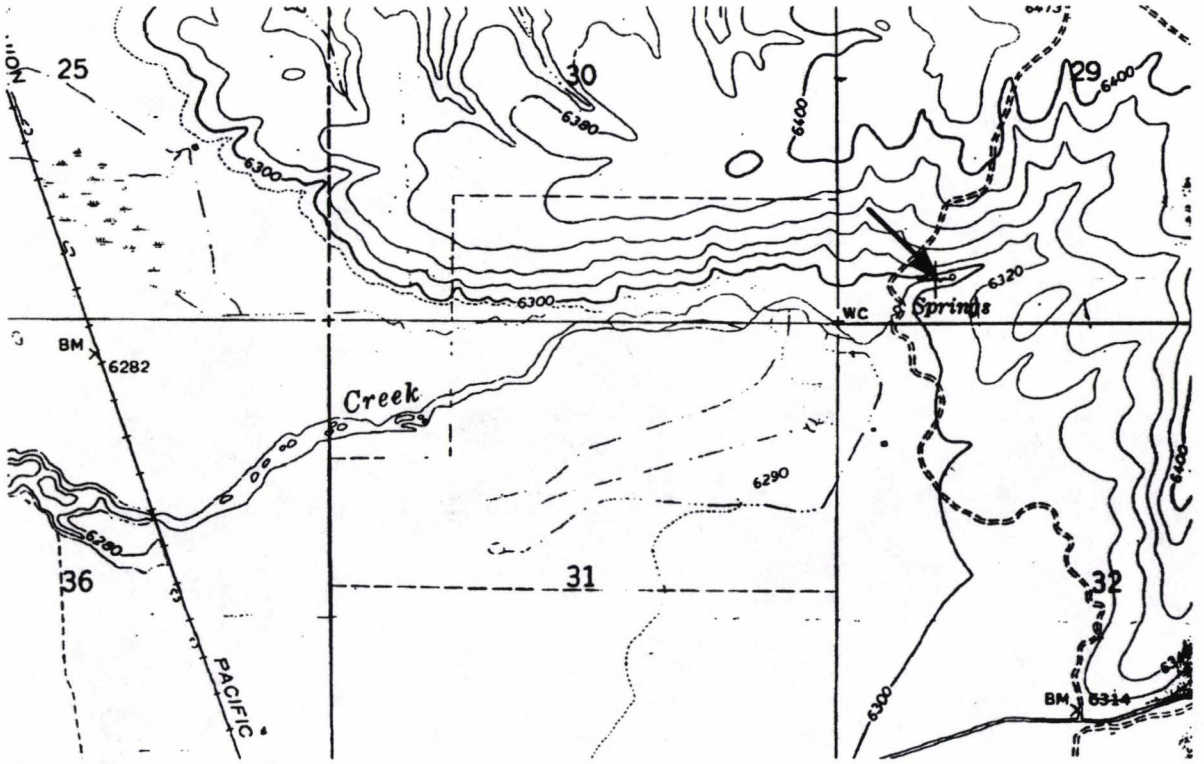
In this report frequent reference is made to the study by Williams (1978) on the various methods of estimating bankfull stage. Below each method is listed and commented upon based upon its applicability in the spring-dominated channels.

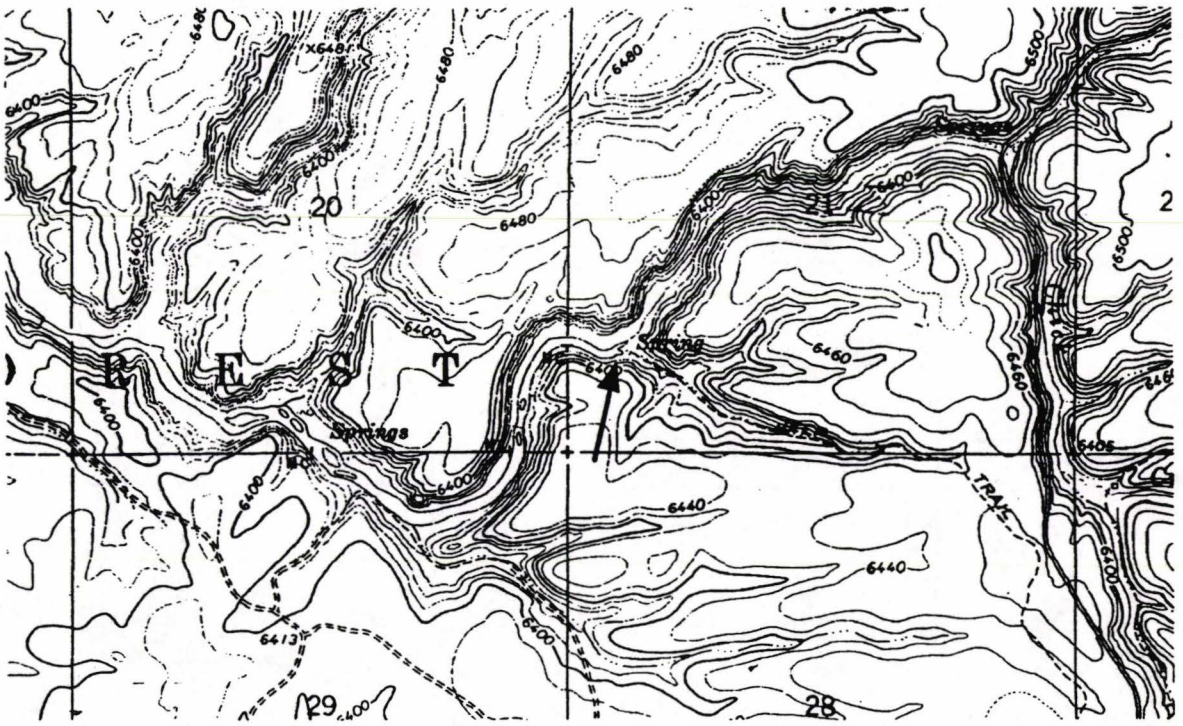
1) the height of the valley flat - seems fine
2) the elevation of the active floodplain - the channels do not migrate much to the floodplain will not be broad

3) the elevation of the low bench - often the bankfull level
4) the elevation of the middle bench - this presumes that there is some lower bench which is not seen in the spring-fed channels
5) the elevation of the most prominent bench - in some of these channels the most prominent bench is a high terrace which is obviously not the bankfull level.
6) the average elevation of the highest surface of the channel bars - channel bars are generally lacking
7) the height of the lower limit of perennial vegetation - this is appears useful but care must be taken because some vegetation seems to grow to the water level (mosses) but for instance pine will generally not grow at the level of bankfull.
8) the upper limit of sand-sized particles in the boundary sediment - I am not comfortable with this in general.
9) the elevation at which the width/depth ratio becomes minimum - this is quantifiably rigorous but may lead one to ignore other evidence.
10) the stage corresponding to the first maximum in the bench index (Riley) - could be useful
11) the stage corresponding to a change in the relation of cross-sectional area to top width - if the channel is wide like many of these spring-dominated channels, the approach can be complicated to interpret.

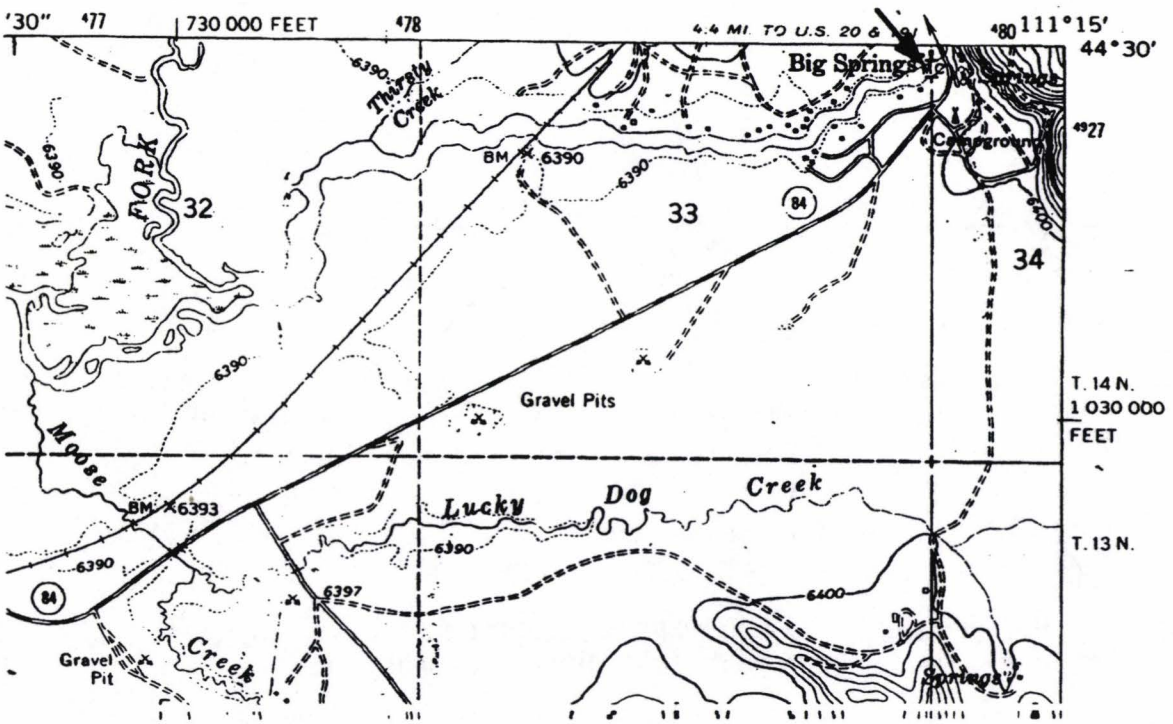
Appendix B- Topographic Maps of the Sites



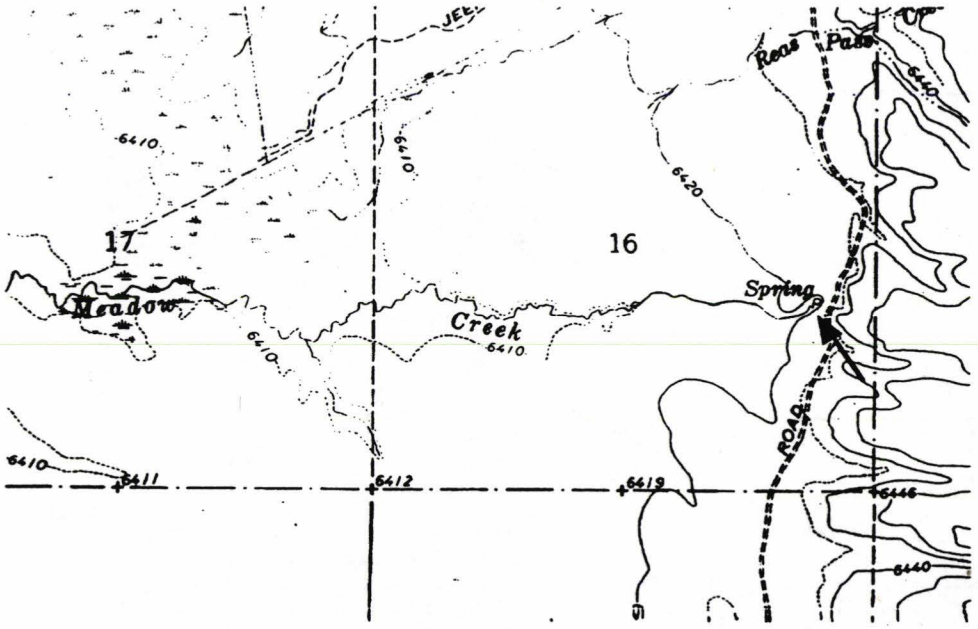
Section of Island Park, ID 7.5-minute series quadrangle showing Toms Creek. Arrow marks the location of the cross section shown in Figure 1.



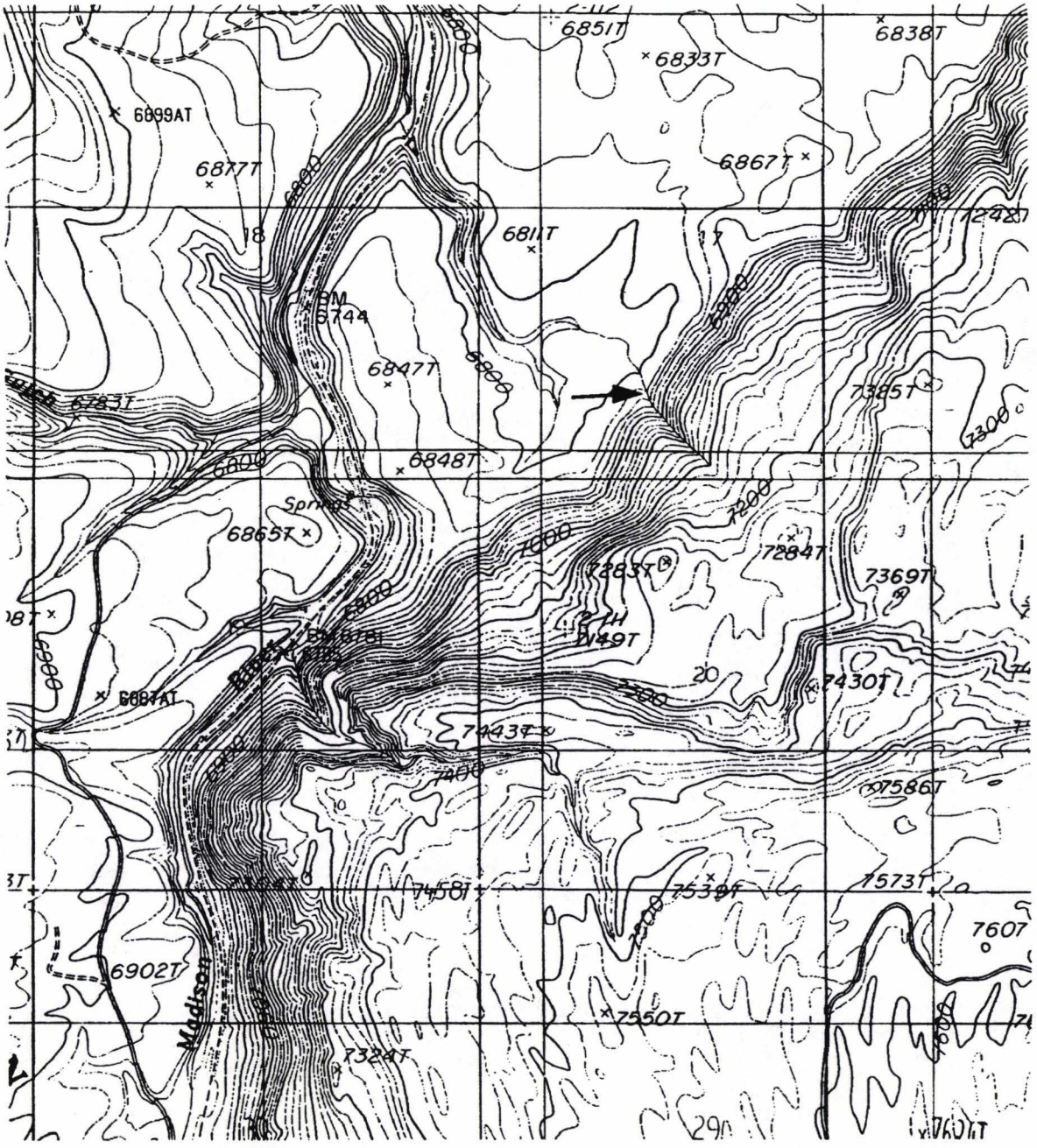
Section of the Island Park, ID 7.5-minute series quadrangle, showing the Buffalo River. Arrow marks the location of the cross section shown in Figure 2.



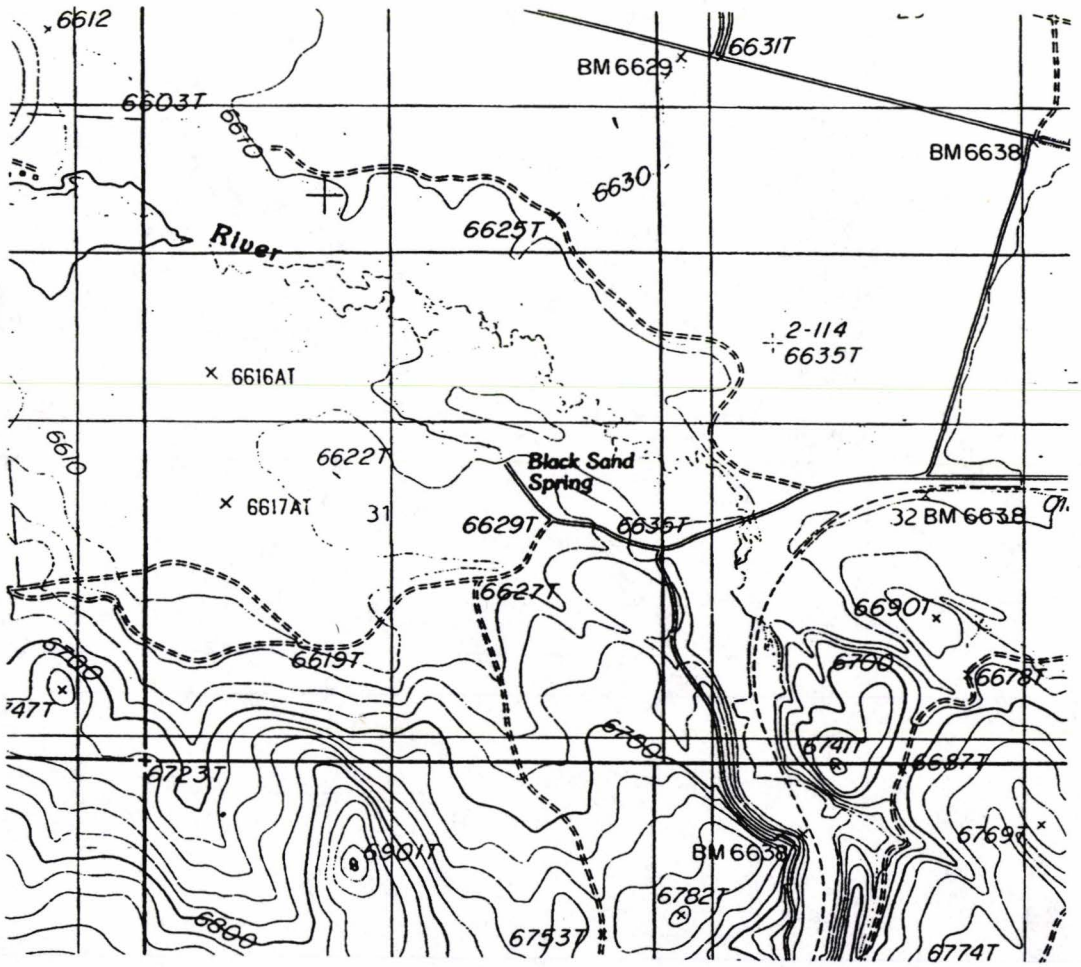
Section of the Island Park, ID, 7.5-minute series quadrangle showing Big Springs. Arrow marks the location of the cross section shown in Figure 3.



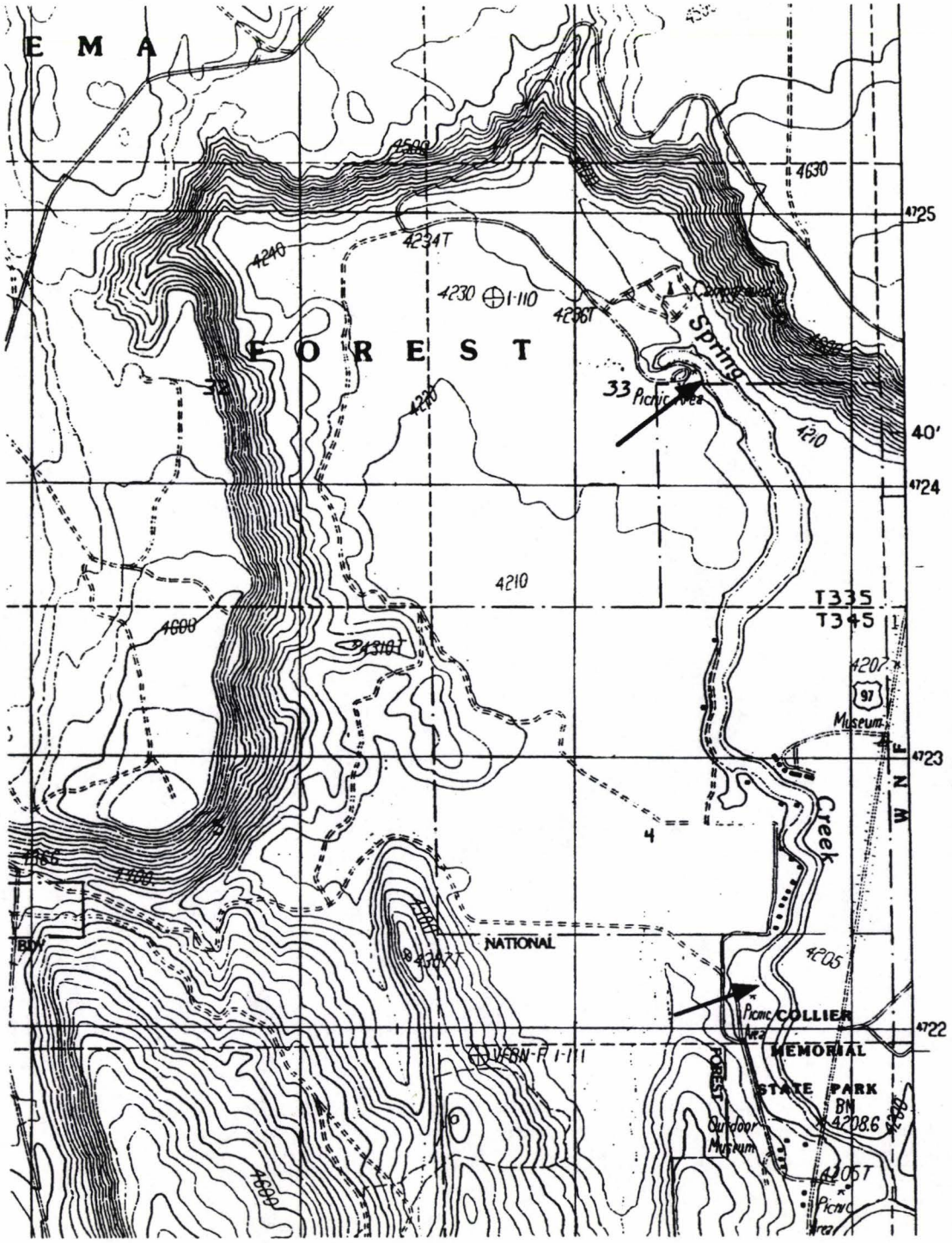
Section of the Big Springs, ID, 7.5-minute series quadrangle showing Meadow Creek. Arrow marks the location of springs at the head of Meadow Creek.



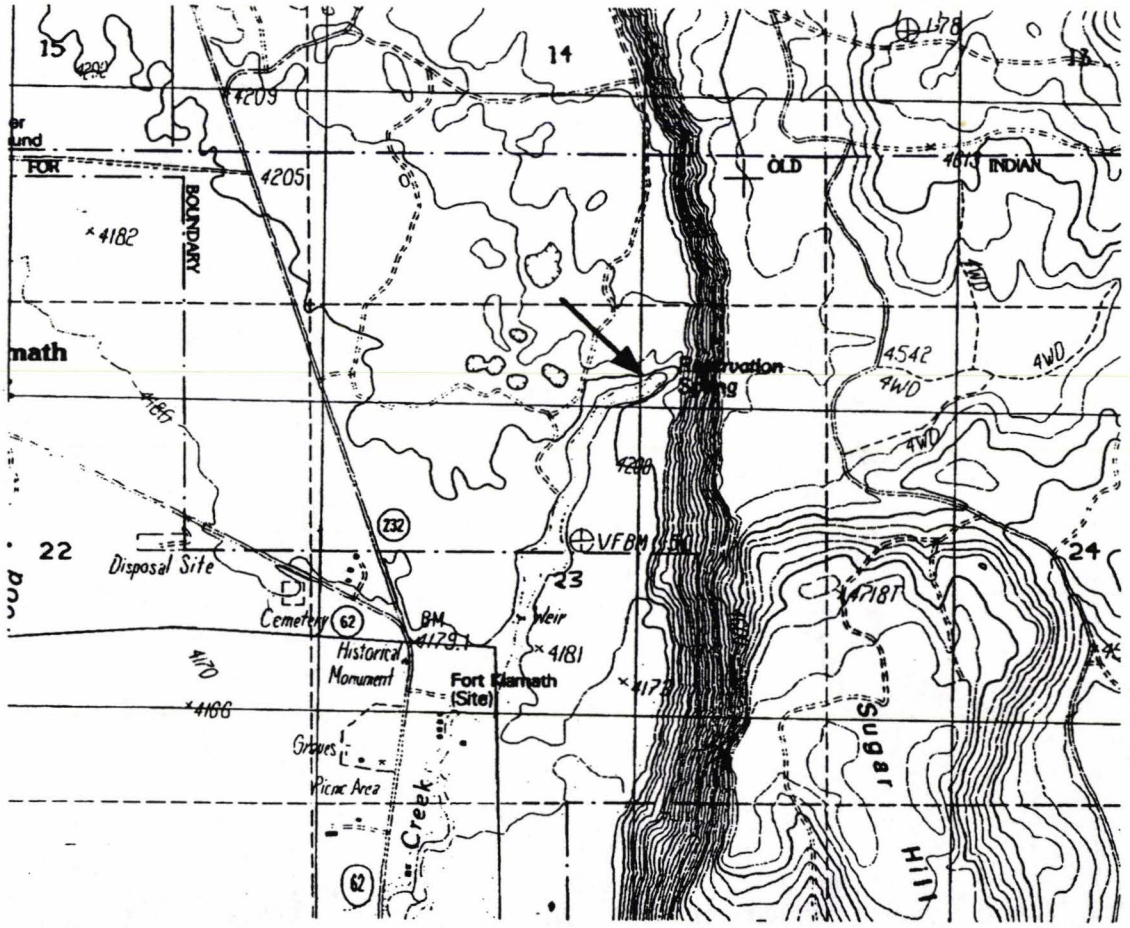
Section of the Reas Pass, ID-MT, 7.5-minute series quadrangle. Arrow points at the approximate location of the cross section of Whiskey Creek, shown in Figure 4.



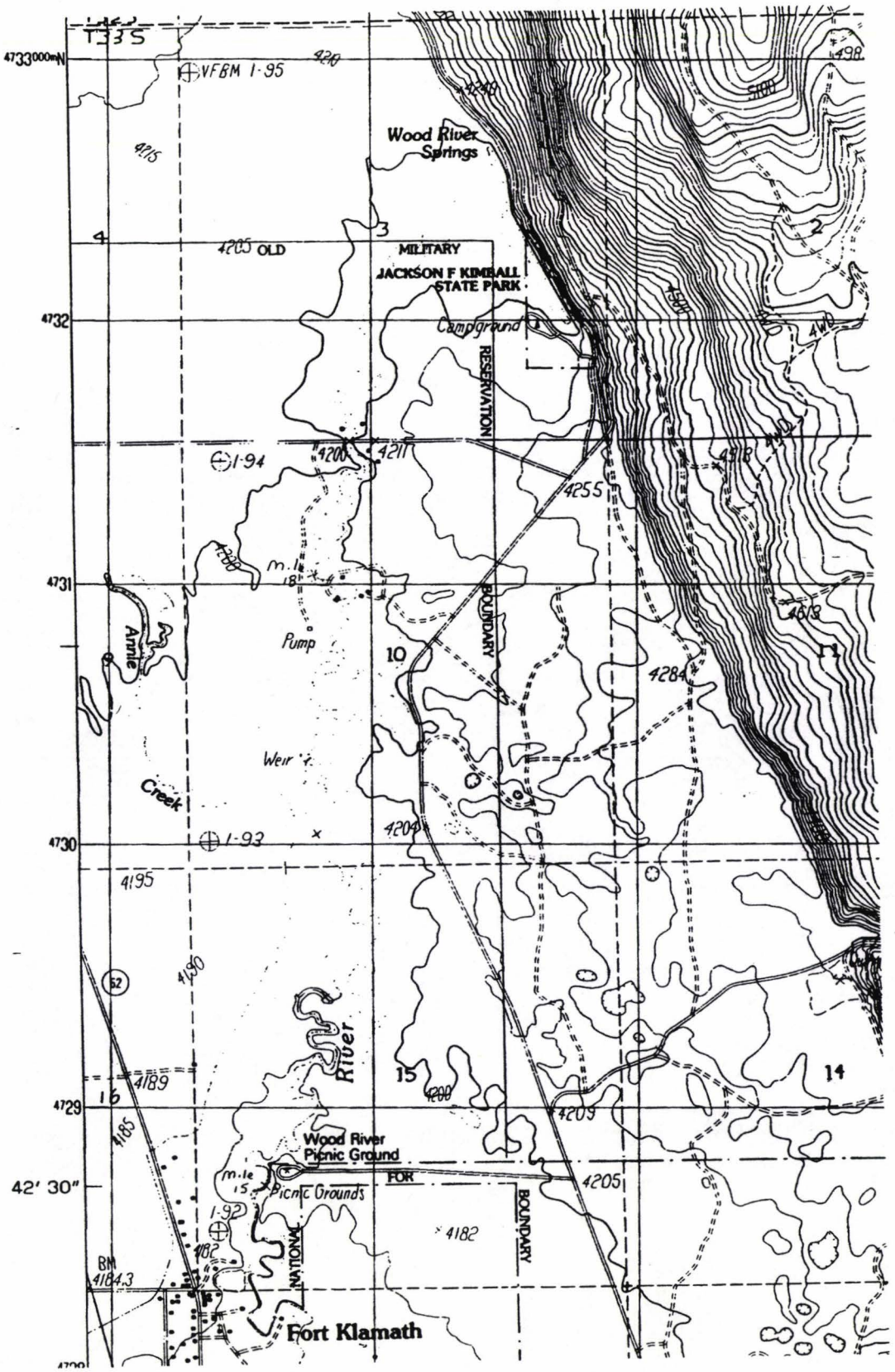
Section of the Madison Arm, MT-ID, 7.5-minute series quadrangle, showing the location of Black Sand Spring.



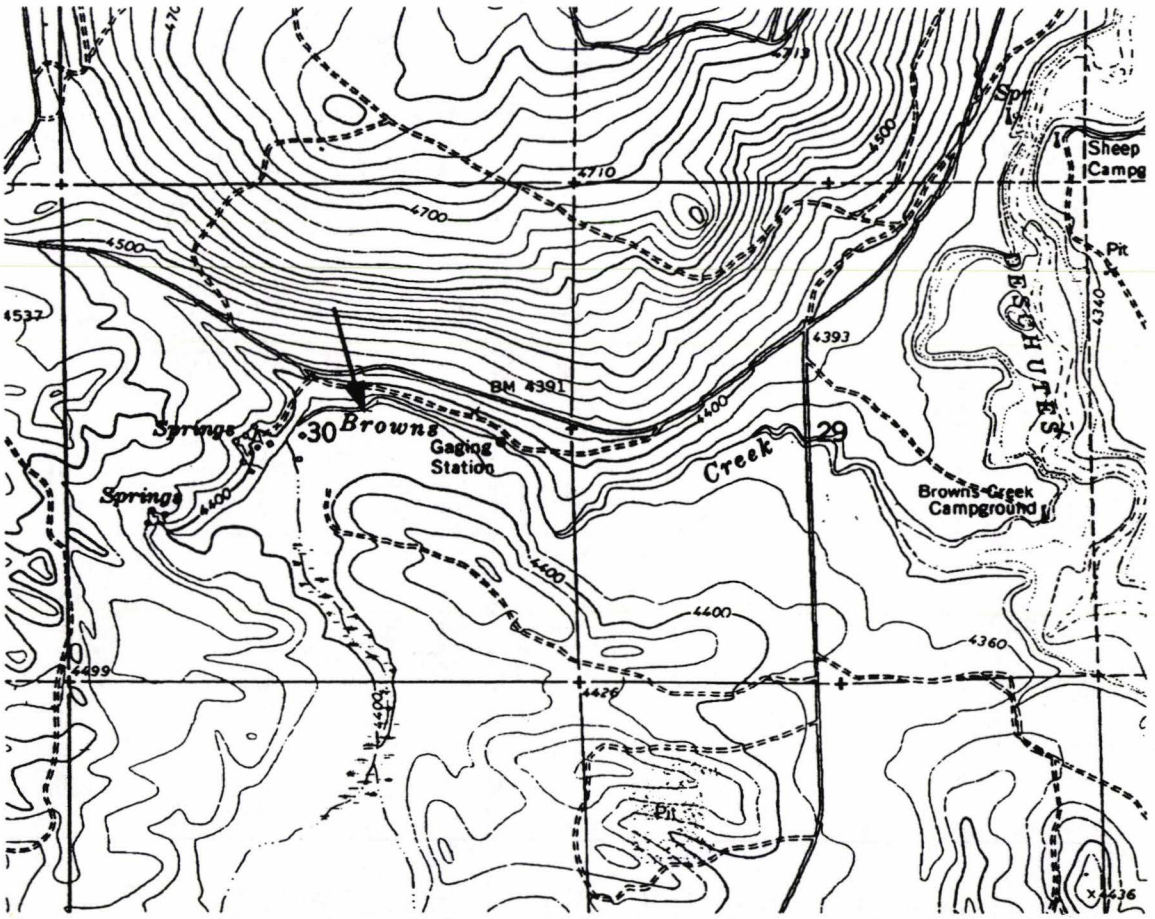
Section of the Klamath Falls, OR 7.5-minute series quadrangle, showing springs at the head of Spring Creek and the location of Collier Memorial State Park. Arrows mark the locations of the cross sections shown in Figures 5 and 6.



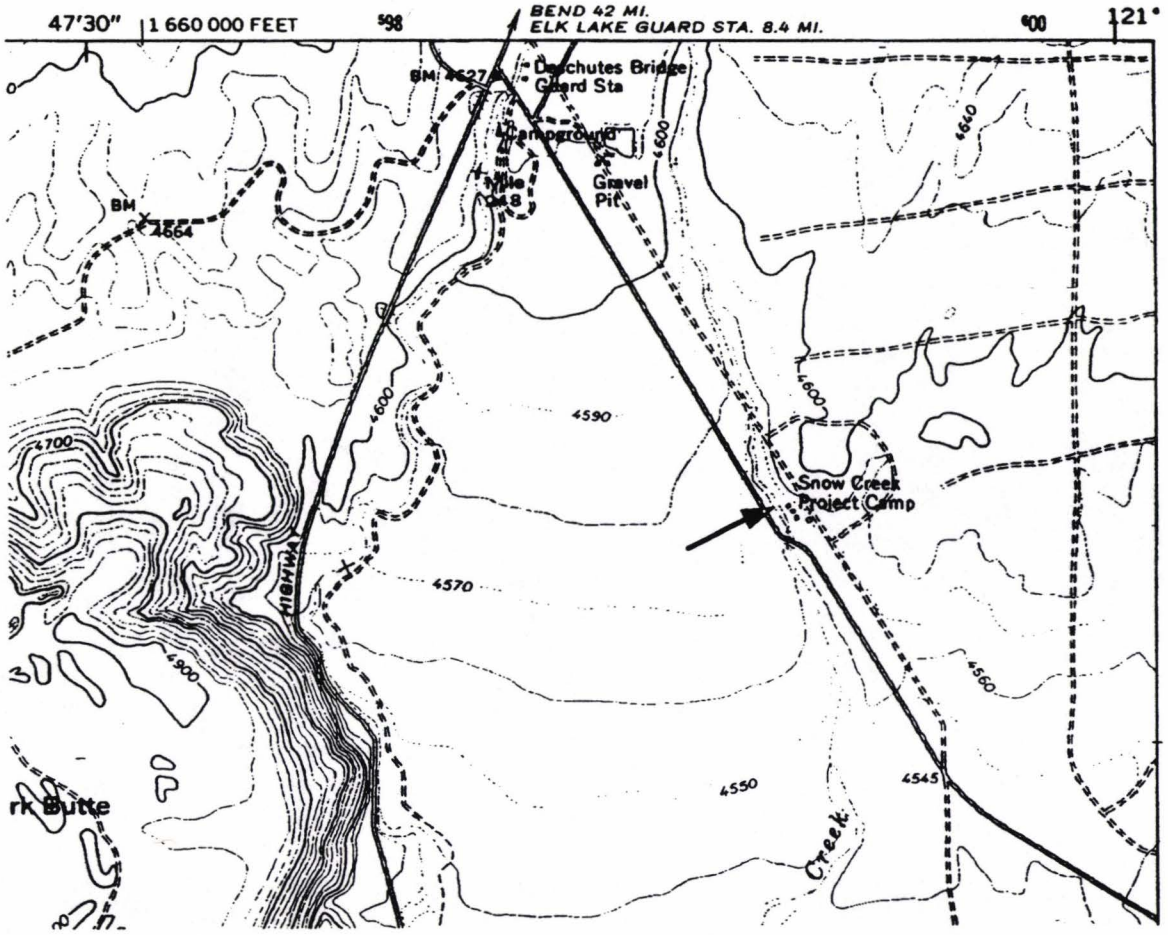
Section of the Fort Klamath, OR 7.5-minute series quadrangle, showing Reservation Spring and Fort Creek. Arrow shows the location of the cross section of Fort Creek, shown in Figure 8.



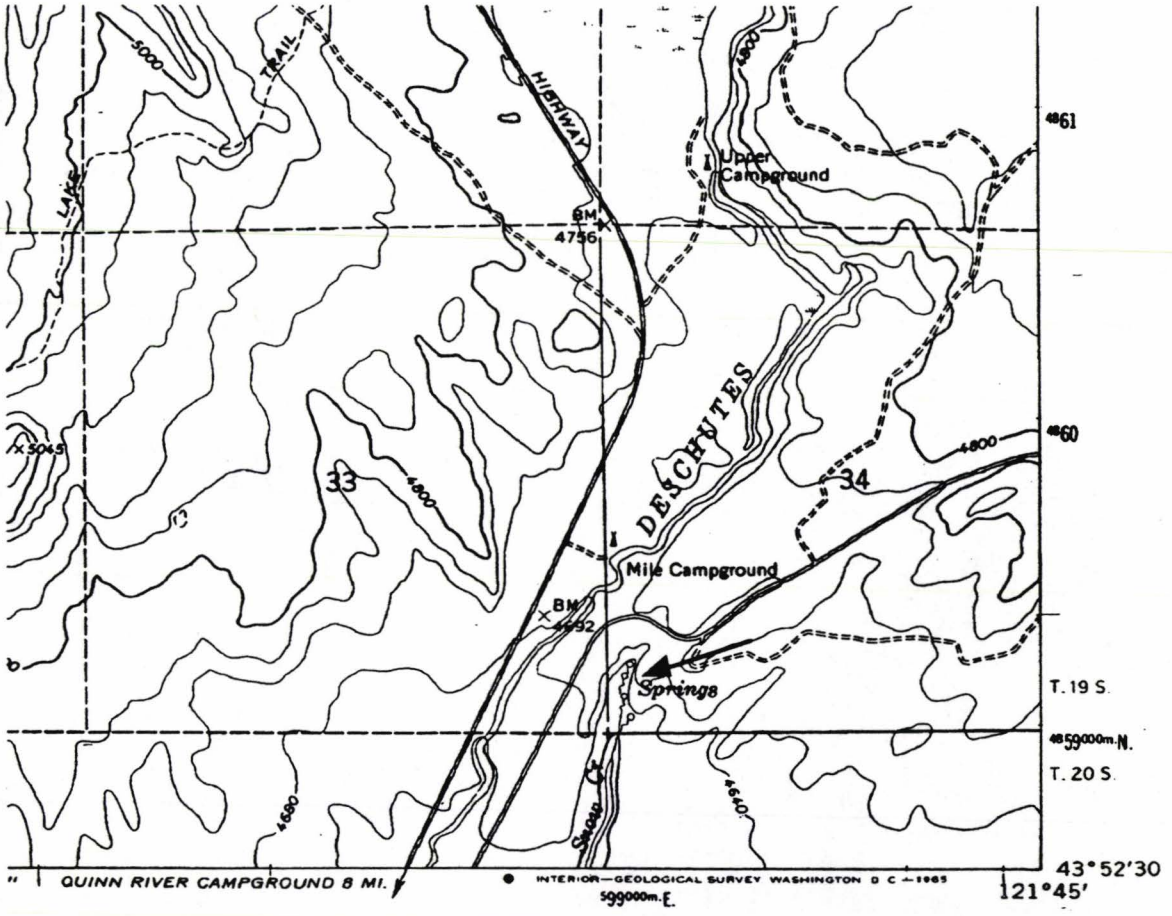
Section of the Fort Klamath, OR 7.5-minute quadrangle, showing the Wood River, Wood River Picnic Grounds and Wood River Springs.



Section of the Davis Mountain, OR, 7.5-minute series quadrangle, showing Browns Creek. Arrow marks the location of the cross section shown in Figure 9.



Section of the Crane Prairie Reservoir, OR, 7.5-minute series quadrangle, showing Snow Creek. Arrow shows the location of the cross section shown in Figure 13.

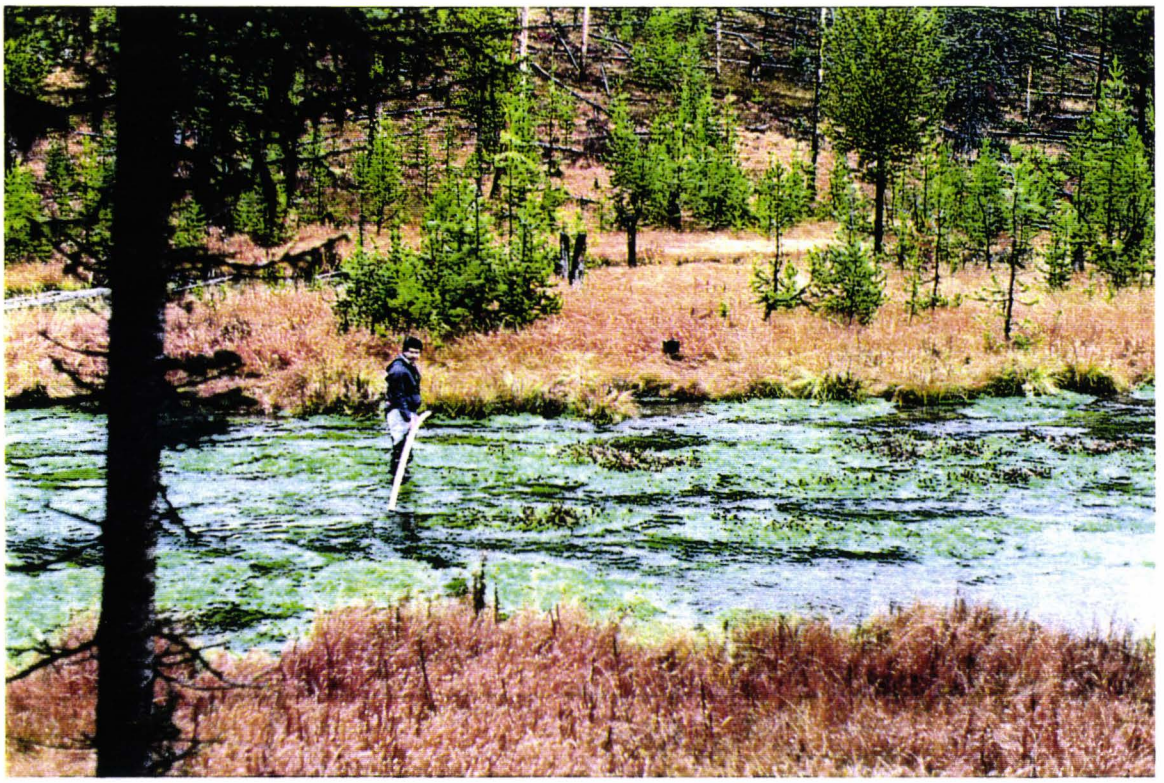


Section of the Elk Lake, OR, 7.5-minute series quadrangle, showing springs at the head of Snow Creek. Arrow points to the location of these springs.

Appendix C- Photos of the Sites

Toms Creek, viewed from the top of the ridge along the right bank.

Big Springs, looking downstream along the right bank.



Buffalo River, viewed from the left bank.

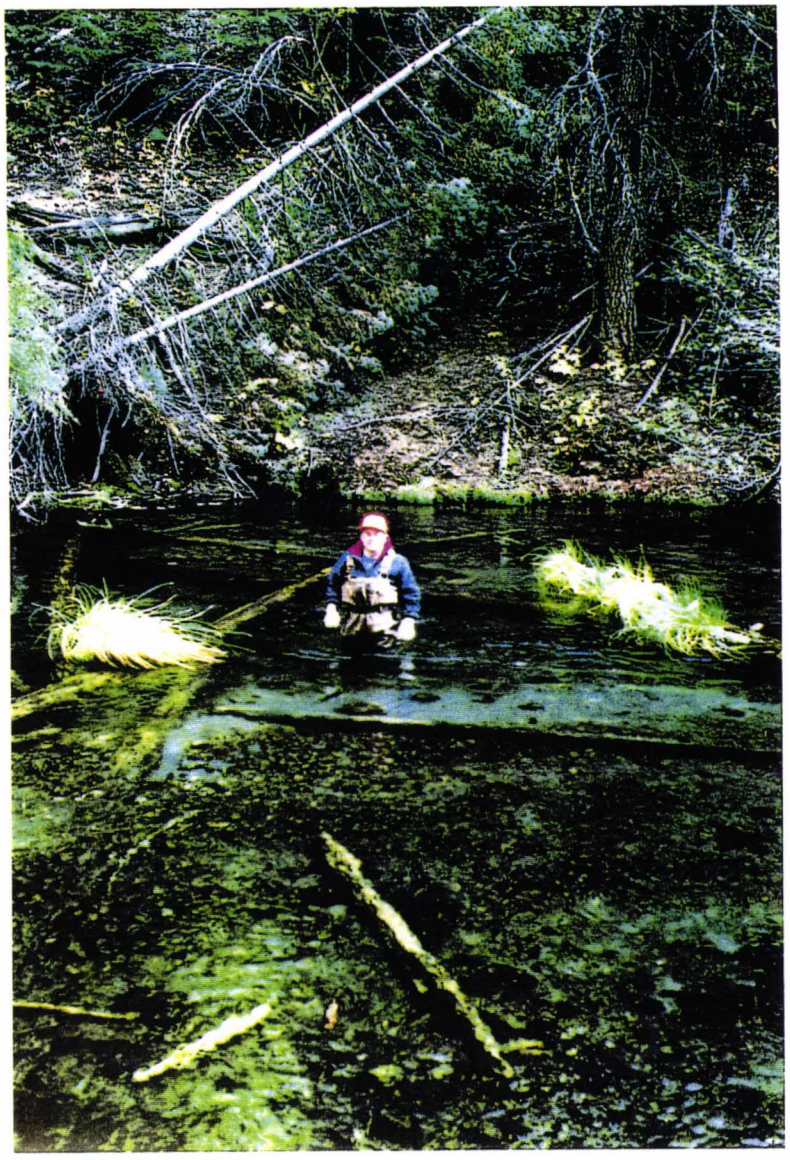
Buffalo River, viewed from the spring head.

Meadow Creek Spring, looking upstream to the spring head.

Whiskey Creek, looking upstream.

Wood River, near the springs.

Wood River, near the Picnic Area.



Reservation Spring, looking at the left bank.

Black Sands Creek, at the head of the springs.

Black Sands Basin Creek, looking downstream.

Browns Creek, looking upstream.

Snow Creek, looking downstream.